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The development of a method of
maintaining constant voltage on
the lights of an electric car

Railway Electrical Engineering

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THE DEVELOPMENT OF A METHOD OF
MAINTAINING CONSTANT VOLTAGE
ON THE LIGHTS OF AN ELECTRIC CAR

BY

ORUS ETHAN GATES
LUDWIG KUMMER

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

RAILWAY ELECTRICAL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED JUNE, 1910.

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36-1804-26

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ENTITLED THE DEVELOPMENT OF A METHOD OF MAINTAINING CONSTANT
VOLTAGE ON THE LIGHTS OF AN ELECTRIC CAR

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in

Railway Electrical Engineering

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168113



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THE DEVELOPMENT OF A METHOD OF MAINTAING CONSTANT
VOLTAGE ON THE LIGHTS OF AN ELECTRIC CAR.

The object of this thesis is to study the problem of lighting electric cars. Recent improvements in interurban electric cars tend toward larger car bodies with luxurious furnishings, but the improvement in lighting has by no means kept pace with other improvements. The chief difficulty in the present system is that when the car starts, or when too many cars are running on a section, the voltage drops causing the lights to go down. Travelling under the best conditions is monotonous and tiresome, and if to this is added a lighting system that at intervals fails to properly illuminate, it is no wonder that people prefer the steam railways for even moderate distances. The chief difficulty in obtaining good car lighting is to keep the voltage on the lamps constant. The distribution of lights is in most cases well taken care of, and designs generally have been liberal enough in the number of lights used. This would give excellent illumination if the lamps burned constantly at their rated candle power. However, electric interurban work necessitates long feeders, and with the best possible design of feeder arrangement, all things considered, it is impossible, without enormous expense, to keep anything like normal voltage at the car. At the start for example, the car takes a heavy current and the line drop increases considerably, causing a sudden dropping off of lamp voltage. This effect is most noticeable on long interurban lines where feeders are designed for an average of one car on a section. In city work the cars are small

and numerous and the feeder system more of a network, so that the increase in current due to the starting has very little effect on the voltage. On alternating current systems, the small currents used cause a small drop, and it is only on systems that have very long transmission lines that the drop in voltage becomes enough to call for a regulating device.

The only method of overcoming this annoying fluctuation of lights is to hold the voltage across the lamps constant. This must be accomplished by some regulating device placed on the car, and the objection of cost is at once raised. However, interurban cars are expensively fitted with good seats, heaters, and other furnishings, and an increase in cost that will bring such beneficial results as this would be well warranted. There are advantages in improved lighting that cannot be reckoned in dollars and cents, but rather in better satisfaction and increased patronage. But even then, there are items of saving under certain systems that will compensate for the increased cost of the apparatus. Take for example the ordinary arc headlight. These lamps are designed to operate on 70 volts. But the voltage on direct current systems is between 500 and 600, and to obtain the desired voltage at the lamp, resistance is placed in series with the lamp. Mr. R. C. Taylor in a paper before the Central Electric Railway Association^{*} gives the power used by the lamps as 315 watts, while the power lost in resistance is 2385 watts. This on a basis of 1200 hours a year and figuring power at .5¢ per kilowatt (a low estimate) gives almost

* Western Electrician. February 16, 1907.

\$15 a year as cost of power lost in resistance for a single arc lamp. This capitalized at 10 percent would allow an expenditure of \$150 for regulating apparatus, without any increase in total cost of operation. In some of the cars used on the Illinois Traction System four arc lights are used with incandescent lamps for interior lighting. These arc lamps are connected in two separate circuits, consisting of two lamps and an iron wire resistance. This, on the basis of Mr. Taylor's figures, with the headlight, gives a power loss in resistance of 6525 watts, which, on the same basis costs \$40 per year. If this power could be saved, quite expensive regulating apparatus could be used without any increase in total operating cost.

The solution of this constant voltage problem has been attempted by many. Innumerable suggestions have been made in the technical press, but curiously enough, up to date, no system has been designed that is in actual operation on electric cars. Many methods are in vogue in steam train lighting, but electric lines would not care to install such expensive systems. The designers of steam car electric lighting, up to 1901 had made little progress, and from that time until 1905 little is written in the technical press of car lighting. However in 1905 and in the few years subsequent, the development was fast, and many new schemes were evolved. Owing to the fact that the steam car had to stand without external power for some time, all systems designed (excepting locomotive drive) involved, and were based, on the use of a storage battery in the car, the power for battery and lights being

furnished by an axle driven generator. This furnished a great electric problem, owing to the fact that the speed of the generator varied thru such a great range and also to the fact that the generator must give constant direction current, regardless of its direction of rotation. For the solution of these two problems numerous mechanical and electrical devices have been designed. The fact that a storage battery is used, cuts down the range necessary for the generator to produce constant voltage (or current) and simplifies the problem a little. But it must be so arranged that the storage battery be charged about as long as it is discharged. The difficulty of keeping the generator output reasonably constant at variable speeds has been overcome in many ways. Purely mechanical and electrical methods have been tried. Among the former is the Stone system, where the drive between the axle and generator slips when the torque has reached a certain value, thus keeping the speed constant at the generator. Cone pulleys and friction drive have also been tried, to give constant generator speed.

The other way, and this is the most common, is to leave the relation between the wheel and generator speed constant and compensate for the change of speed by regulating the excitation of the machine. Some systems have an auxiliary machine that bucks the orginial machine more and more as the speed increases. In some cases this bucker is placed in the field of the machine. The danger with many of these systems is that at very high speeds the bucking force may completely over-come and reverse

the originally predominating force. A purely electrical solution is to have a differential compound generator, with the shunt field predominating. The performance of such a machine is not independent of the speed, but it is better than an ordinary shunt machine. Even with an ordinary shunt machine, the field is weakened by armature reaction when the current is heavy, and this effect is greater with a "poor" machine than with a "good" one. For the solution of the problem of uni-directional current, one finds many devices, from the simple brush shift (one pole) thru the rotation of armature and brush friction, to complicated devices with worms and friction drive. Even air and water have been used for this purpose, to say nothing of electro-mechanical devices. In the "D" trains of the Prussian States railroad*, the current in the lamps was regulated thru a medium range by means of resistances made of iron wire which were connected in series with the lamps, across the storage battery.

A more recent summary of American practice on steam rail-ways is given in December 5, 1908 issue (page 1218) of the Electrical World. The type "A" equipment has a shunt generator whose field circuit has a motor operated rheostat with ratchet and pawls which are controlled by a solenoid carrying the generator current. The lamp current is regulated by a permanent resistance which is cut in series with the lamp. The resistor is divided into sec-tions, and while the lamps are protected from a high voltage, fluctuation of lamps are noticeable when resistors are cut in and

*Electrotechnische Zeitschrift Page 393.

out. In the old Gould equipment, the regulation depended upon the slipping of the belt. This system required two storage batteries, one being charged while the other was connected to the lamps. Several patents have been taken out and some experiments made, with devices using compressed air to operate rheostats with air valves controlled by solenoids. No satisfactory practical results have been obtained with these devices. In the United States equipment, the voltage regulation of the generator is accomplished by varying the pressure on a pile of carbon discs in the field circuit, by means of a solenoid which carries the generator current. The Newbold device has a field rheostat which is operated by a solenoid. The solenoid is differential wound, one coil carrying the generator current and the other the lamp current. This causes the generator load to increase when lamps are being used. The Bliss system, which is subsequently more fully described, regulates the field and lamp current by a motor driven bucker. In the Consolidated type "D" equipment, the voltage regulation of the generator is accomplished by an automatically operated field rheostat. The voltage at lamps is maintained within a variation of 1 to 1.5 volts by a small motor and an electro-magnetically operated device which cuts a suitable resistance in or out. This regulation is positive and maintains the voltage at lamps constant regardless of any change of conditions in the other parts of the system. The only deficiency is that the action is not instantaneous. When a considerable number of lamps are

turned on or off, a few seconds are required for the rheostat to adjust itself.

In the following pages diagrams and descriptions are given of several train lighting and regulating systems, both foreign and American. These systems were chosen, not because they are the best, but because they are, to a certain extent, representative of those systems which are at present in successful operation. It is not suggested that any of these systems might be used for the lighting of electric cars, but rather, the ideas embodied in these schemes are to help in the solution of the problems of electric car lighting. It is for this reason that the Rosenberg generator used in the system of the Allgemeine Elektricitats Gesellschaft is described in detail and theory.

As for the lighting of electric interurban cars themselves, we find very little progress made. Suggestions have not been lacking, but the suggestions when investigated for further details, or when put into practice, fail to give proper results. Mr. R.C. Taylor, in a paper before the Central Electric Railway Association at Indianapolis, discusses the matter and comes to the conclusion that, in the event of no satisfactory regulator being produced, the importance of good lighting would warrant the installation of a motor-generator set. He adds also that, "This could be well taken care of in connection with compressor motor. This motor could be designed for constant speed at variable voltage and of such capacity as to run the air compressor and lighting circuit. The lighting generator could be mounted on the motor shaft and no additional

bearings or frame would be required. On the compressor gear would be mounted an automatic air-operated clutch. The operation of the machine would then be this: When the lights are burning, the motor and generator would run continuously. The automatic air operated clutch would throw the compressor part of the device out, and in to meet the demands for compressed air. When the lights were not required, the operation of the compressor would be the same as at present, starting and stopping the motor. This device is extremely simple, efficient and of low cost." Assuming that the "automatic air operated clutch" would act satisfactorily, it would cause considerable strain on the motor to throw the clutch in when the motor was running at full speed. It would also cause the speed to change, causing fluctuation of lights. The design of a motor that will run at constant speed with varying load and varying voltage is easier to suggest than to perform, especially when it is desirable that it have a series characteristic, in so far as starting on full voltage is concerned. The air compressor motor at present is designed to operate at normal voltage, the speed and current merely dropping off when the voltage drops, and increasing again as the voltage increases. However in the suggested design, the motor would have to be made large enough to run the compressor (and generator) at normal speed, regardless of the drop in voltage. At low voltage the motor would take an excess of current and that just at the time when the load was at the peak. This is true also if the "constant speed" motor is connected to the generator only, but not to nearly as large an extent.

The complication of this scheme, and the increased size and complexity of apparatus, aside from the design of the "constant speed" motor, would in my opinion render this scheme far from being "extremely simple, efficient and of low cost."

Among other schemes, more for economical than for efficient lighting, is the suggestion that the headlight be put in series with the lamps, thus saving the power lost in resistance. An arc headlight takes 4.5 to 5 amperes and, when in series with 4-lamp sets, would require 36 to 40 incandescent lamps or their equal in resistance to be used. This would effect a saving and give good service -- until the voltage dropped and the arc went out.

Another author suggests that a device be arranged, whereby the lamps burn five in series when trolley potential is normal. When voltage drops an automatic regulator should drop the fifth lamp and substitute enough resistance to keep the current constant. When the voltage dropped sufficiently the fourth lamp was to be dropped. "This controller or regulator should operate a rheostat" the author remarks. Controllers and resistances for practical work have steps and each change of resistance, together with the natural lag of the solenoid or coil, would cause a fluctuation of lights. A big drop in voltage would cause a big drop in the lamps until the regulator was altered by the controlling device. This same author sarcastically remarks that, "If the electrical engineers that are concerned with this problem would apply themselves with the zeal and energy that characterized the labors of the men

that struggled with the quadruplex telegraph, the wasteful features connected with the operation of the trolley car, if they are not wholly exterminated, will be minimized to a great extent!"

The suggestion, that the lamps be driven from a low voltage battery which is to be charged by the current thru the compressor motor does not appear feasible when investigated. In the first place, operating officials have an objection to using storage batteries on electric cars. They are expensive both in first cost and in maintenance. They have the great advantage that the lights will burn even after the trolley leaves the wire, thus permitting the tail lights to be electrically lighted. If the battery is of about 70 volts, it could also be used for head lighting, eliminating the rheostat losses incident to it. However, the difficulty of charging the storage battery shows that the plan is not feasible. Assume, say 35-16 candle power lamps, and a 4 H.P. pump on 550 volts, with a 30 volt storage battery to be charged. The battery current when lighting the incandescent lights will be about $\frac{(35).(55)}{30} = 64$ amperes. The battery will need a charging voltage of about 40 volts, leaving 510 volts for the pump. The pump, when running on this voltage, will take a current of say 2 amperes per H.P. = 8 amperes. Thus to charge the battery, the compressor motor must run $\frac{64}{8} = 8$ times as long as the lamps are used. If a 70 volt battery is used, the conditions are better but the battery is more expensive. In this case, the headlight would be run from the battery, taking say 5 amperes, while the incandescent light current falls to $(64) \frac{70}{70} = 27$ amperes making a total of 32 amperes.

The pump would be operating at about 470 volts taking a current of about 8.5 amperes. This means that the pump must run $\frac{32}{8.5} = 3.8$ times as long as the battery discharges. Taking a lamp run of four hours, this means that during the day, the pump must run 15 hours. This is manifestly impossible under ordinary operating conditions, as the car itself is seldom in operation for a much longer time each day, and the pump works considerably less than half the time. Another difficulty is that the battery could not be charged while the pumps were being used without ^{some} complicated auxiliary device to prevent the voltage at the lamps from changing while the battery was being charged in series with the pump, across the variable voltage. An increase in voltage of the storage battery would bring the scheme nearer the possibility of operation, but the increased cost would prevent the use of the device.

THE AICHELE TRAIN LIGHTING SYSTEM.

The Brown Bovéen and Co. in the January 26, 1905 number of the Electrotechnische Zeitschrift describes the construction and operation of a new car lighting system. The system is designed for axle lighting and is used principally on steam cars. Without going into very much detail, the system consists of an axle generator, a storage battery, a battery cut-in and cut-out, a field regulating device, and several preventive magnets. The generator is of the shunt type, the field regulator compensating for all changes in speed. The regulator is the keystone of this system. It consists of a series of resistances with contacts arranged in a circle. Playing over these contacts, is an arm which is operated thru gearing, by a small motor. The motor field has three windings, the generator current flowing thru one, (C, Plate 1), the lamp current thru the second, (B), and the motor current thru the third, (A). An auxiliary magnet, to the right, has two windings, D and E, both operating in the same direction. The generator is axle driven, being of the shunt type. The regulator resistance is in series with the field and keeps the voltage constant by regulating the field. The operation is as follows. When the car is standing still, the generator is not generating, the contact F is down, and the lamps are directly across the storage battery when switch S is closed. The rotating arm is at G, the first contact, all resistance being cut out when the car is at rest. When the car starts up, the generator, being shunt wound, builds up. The coil D of the auxiliary magnet is directly across the generator, and when the voltage has

built up to the proper point, the current in the circuit causes it to pick up and close the contact F. During this time also, the field A and the armature of the motor have been in series across the generator, the current thru them being in such a direction as to tend to move the contact arm in a clockwise direction. But the arm already is in its limiting position so it does not move. With the closing of contact F, the strength of magnet DE is increased due to the current thru E, and the pressure at contact F is increased. From E, the generator current flows thru winding C, in such a direction as to oppose the action of A. If now the battery voltage is higher than the generator voltage, the lamps will take current thru winding B from both battery and generator. As B has approximately the same number of turns as C, and as it acts in same direction as A, the resulting pole from all three windings will be in the direction of A, and the contact arm remains at G. When the speed increases so that the generator voltage is greater than the battery voltage, the generator current will divide after passing thru C, part going to charge the battery, and the remaining portion passing thru B. Thus it is evident that the current thru C is larger than that thru B. The coils of the motor are so designed, that when the proper voltage has been reached, the battery plus lamp current thru C, will just counteract the lamp current thru B plus motor current thru A. An increase in generator voltage then will cause both light and battery current to increase. But the current thru C will increase faster than that thru B, the effect being to reverse the field. This reverses the motor, and the

contact arm moves in a counter-clockwise direction, reducing the field of the generator. This motor action continues until there is again a balance between currents in C, B, and A. Thus, as the car speeds up, the contact arm moves slowly counter-clockwise, the resistance values being designed to take care of maximum speed. When the generator begins to slow down, the field of the motor is reversed and works again in the direction of A, until the proper amount of resistance has been cut out.

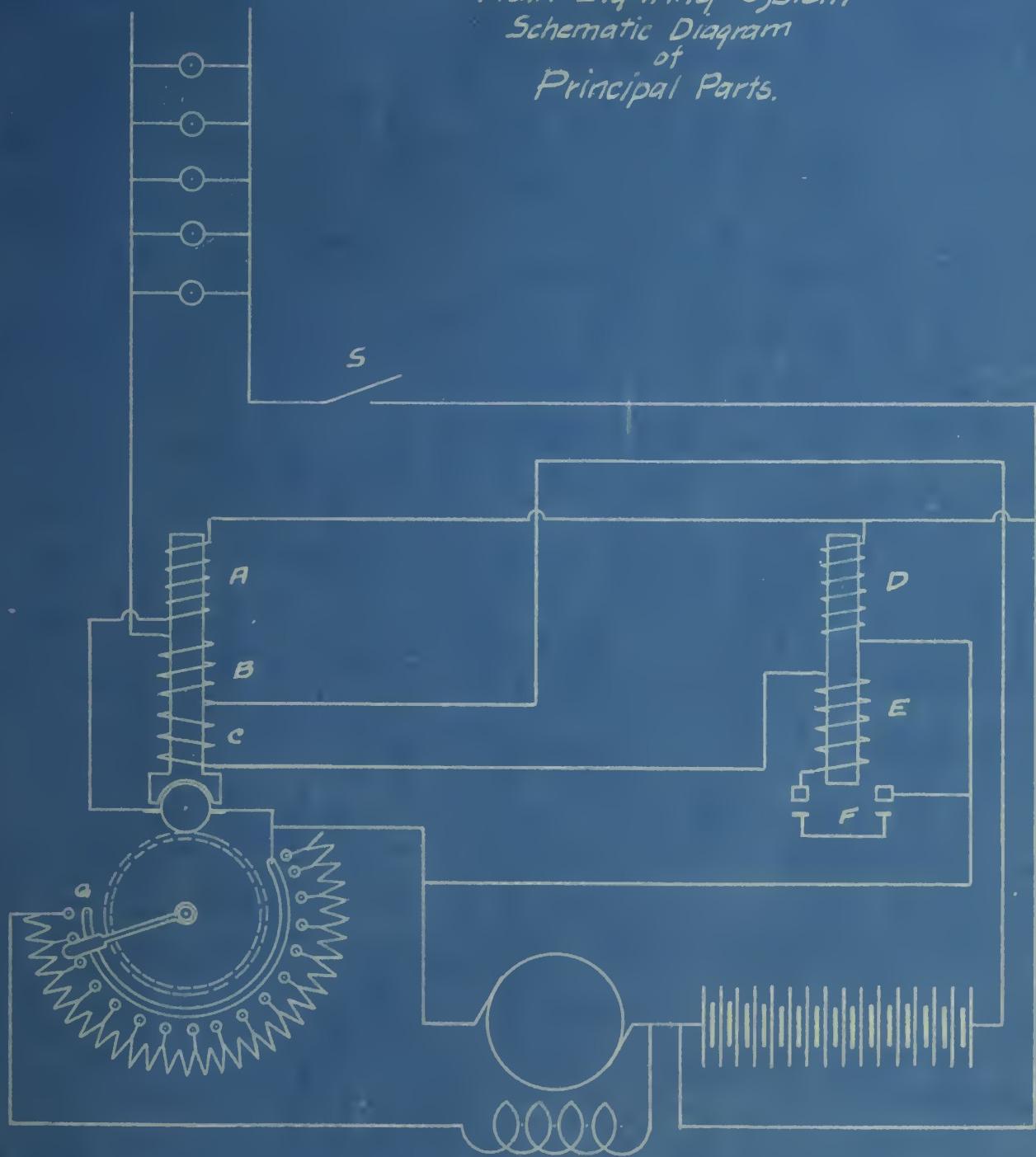
By a complicated scheme of auxiliary relays and resistance not shown in the diagram, the number of lamps used can be varied without affecting the voltage. From the connections as they stand, it is evident that the only effect of decreasing the lamp current will be to decrease the battery current, causing a slightly lower voltage. This follows from the fact that, with a slight increase of generator voltage, the smaller current flowing thru B, due to fewer lamps, would allow C to reverse the motor with less current. As it requires an increase of voltage to increase the battery current, this reversal will take place at a lower voltage than with full number of lamps burning. Various preventive magnets have been put in the circuit such as battery over-charge, and battery break magnets. It will be seen that should an open circuit occur in the battery, windings C and B would neutralize each other while A would bring the contact arm back to G. This would destroy the regulation and put the lamps across the generator which having its field resistance cut out would develop dangerously high voltages at high speeds. A magnet placed in the lamp circuit breaks the

generator field when the lamp current reaches a dangerous value. A spring catch holds the field open until the break is repaired.

In the trial test which was made on a car of the Schweizer Bundesbahne, the following results were obtained. One hundred lamps were supplied. The battery consisted of 18 cells(36 volts) with a capacity of 90 to 100 ampere-hours at a 10 hour discharge. The terminal voltage of the battery varied 1.8 volts between the condition of full charge and the condition of discharge after a 10 hour run at 10 amperes. Under these conditions, with recording instruments, a maximum voltage variation of not quite ± 4 volts was obtained, while the generator current varied only by ± 5 amperes up to a speed of 54 miles per hour. More recent improvements reduce the voltage variation to ± 3 (8.3%), and the current variation to 2.5 amperes.

This system, being an axle lighting system is applicable to either steam or electrical roads. While the variation in voltage is low, the cost of storage batteries and regulator, to say nothing of the maintainance and the trouble caused by complicated mechanism is rather too great an item to permit of its extensive application on electric cars.

THE AICHELE
Train Lighting System
Schematic Diagram
of
Principal Parts.



THE LEITNER LUCAS TRAIN LIGHTING SYSTEM.

In this system of axle lighting, which is used mostly by British railroads, the regulation of voltage at variable speeds is accomplished by means of an auxiliary machine on the same shaft as the generator, which, together with some resistances of positive and negative temperature coefficients, varies the field current of the generator. The cutting in and out of the battery is accomplished by an electromagnet switch.

The schematic diagram of connections is shown in Plate-2. The generator A, which is belt driven from the axle, has a differential field, consisting of a series winding C and a shunt winding D. The shunt field which is predominating, has a relatively low resistance. Direct connected to A is the armature of the bucker B which is so connected as to tend to demagnetize or buck the current in field D. This auxiliary bucker has also a series field F and a shunt field G, working cumulatively. Connected in series with the main field D of the generator, is the armature and series field of the bucker, in parallel with a resistance E which has a marked positive temperature coefficient. This resistance consists of fine iron wire, and is of the general form of the resistance used in the Nernst lamp. Several of these resistances are put in parallel to give the proper current carrying capacity. The shunt field G, of the bucker is in series with a resistance which has a negative temperature coefficient. This generally consists of several ordinary carbon filament lamps connected in parallel.

The operation is as follows. When A is generating, the

current, after passing thru C, divides, part going to the battery and part thru the shunt field. Of the current thru the shunt field, part goes thru resistance E and part thru the bucker B with its series field. This current tends to run the bucker as a motor, the counter E.M.F. being opposite in direction to the current. If the speed of A and B is low, the counter E.M.F. generated in B is low, and the voltage across its terminals, and therefore across E, is low. The resistance of E is therefore low, and both E and B have little retarding effect on the current thru D. Thus D is practically shunted directly across the armature (and field), and the generator is excited to a maximum. At increasing speed, the counter E.M.F. of B increases, and the voltage across E increases, causing the resistance to increase. B is also taking less current at the higher speed and the current thru D becomes less. From this it is seen that, with increasing speed, the field D becomes weaker and the E.M.F. generated in A is held constant as the speed increases. At a certain maximum speed, the E.M.F. of A actually decreases. This effect is aided by the shunt field G of the bucker. This field is connected across the terminals of the generator. Due to the resistance of the negative coefficient in the circuit, an increase of generator voltage will cause an even greater increase in current, and the bucker B will have its field increased, causing an increased counter E.M.F. The smaller resistance E is made, the greater will be the balancing voltage of the generator, while the smaller the resistance W is made, the smaller will be the balancing voltage. Thus by adjusting these two resistances, the

generator voltage can, within limits, be adjusted to any desired value.

The arrangement for cutting the battery in and out is shown diagrammatically in Plate 2. This consists of a movable armature I, and two poles H and J with separate windings. Attached to the armature is the arm R with contacts a and b.

Before the action of the apparatus is described it should be here stated that the reversal of connections, due to reversed motion of the car and the necessity of constant direction current, is accomplished by mechanical means. This change is also accompanied by a shifting of the brushes to prevent sparking.

With the car starting up, the connections and apparatus are in the position shown. The residual magnetism and shunt field build up the generator, and current flows thru H, I, over E and F back to h. At a certain low value this current thru H and I causes the armature and arm R to turn down, closing the contacts at G. This allows current to flow thru J, a, battery to f and h. Also current flows from G over W, G to f and h. The higher the voltage of A rises, the stronger is the current thru H, I and J, and the more firmly the arm R is held down. This is the condition as long as the generator voltage is higher than the battery voltage. If the voltage of A is less than the battery voltage, the current thru J will be reversed; the arm R will turn in the opposite direction, and the contact at G will be broken. But this would bring back the original condition, and the contact at G would be made

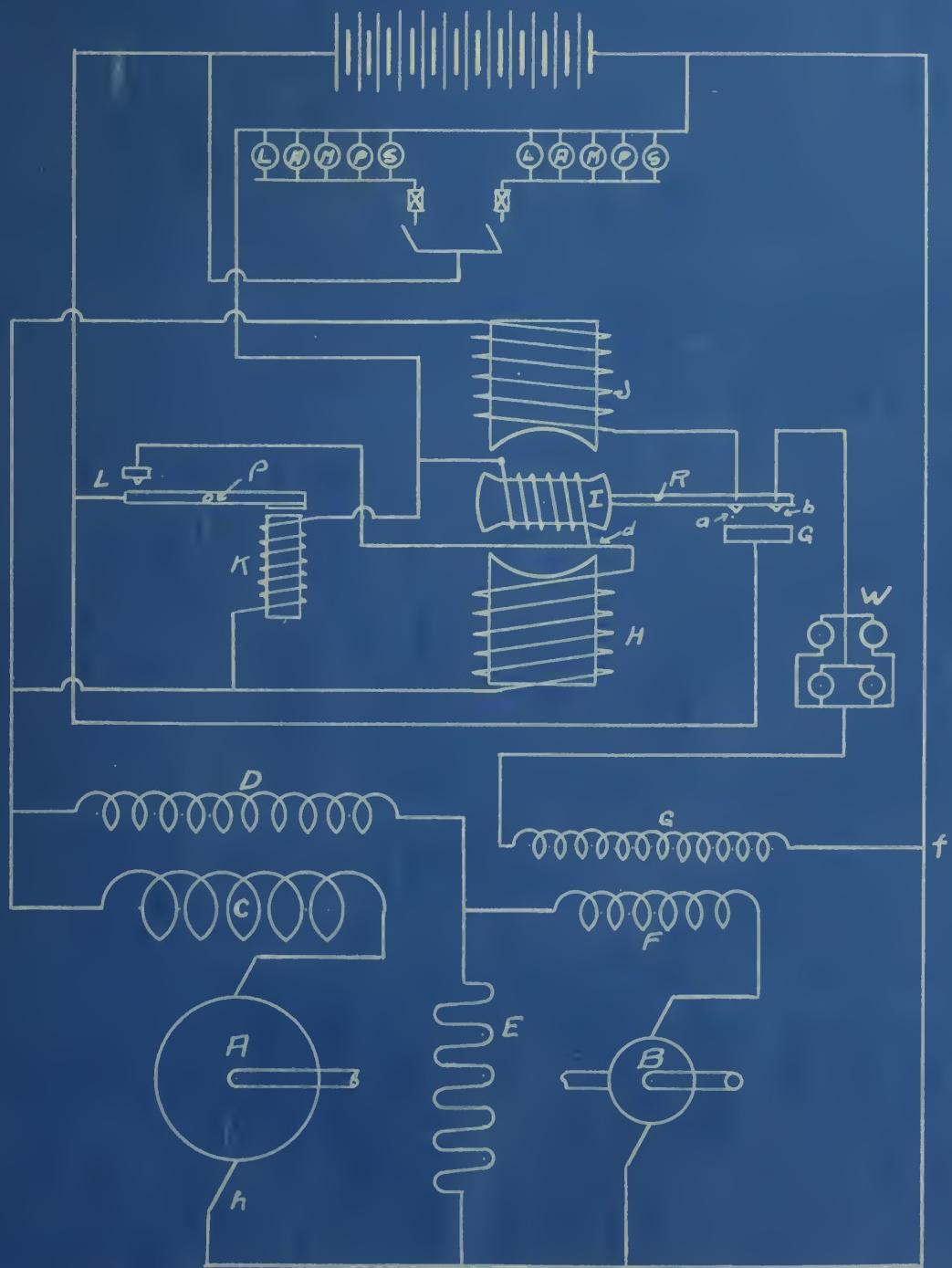
and broken constantly, while the generator was running under battery voltage. To prevent this, the device LPK is introduced. At a certain generator voltage, K, being across the line, attracts P, closing the contact L. The magnet holds the contact now until the voltage of generator sinks to half of its original value, (the point of closing L). With L closed, upon the generator voltage dropping below battery voltage, the current flows in a reverse thru direction thru the battery, going ^{thru} _a and J in the reverse direction as described before. Also, the current branches and goes thru L direction to d, and in opposite ^{thru} _a H, back to the other side of the battery, while part goes thru I in the original direction and back to the other side of the battery. This causes R, to move in the opposite direction and contacts at G are broken, as long as L remains closed. But L remains closed until the current sinks to $1/4$ the value at which R will be closed, that is, at which the generator is thrown into the main circuit. The action of this auxiliary device is very quick when the generator slows up. The contact L opens at once and prevents an excess current over L and I. As soon as the generator voltage again exceeds the battery voltage, the contacts at L and G close again. Thus it will be seen, that the generator has a constant voltage over a wide range of speed, and that as soon as it runs over the lower speed limit, the battery is automatically thrown across the generator to be loaded. Also, at this point, the lamps stop taking current from storage battery and are thrown on the generator.

Eye witnesses state that hardly any difference in the

candle power of the lamps was observed in running from speeds of zero up to 75 M.P.H. Recently a motor regulator and other auxiliary devices were added to this system where extra good regulation was desired, and where the battery voltage was to be constant regardless of the number of lamps in the circuit. Provision is also made in the later arrangement to prevent overcharging of the battery.

PLATE 2

LEITNER-LUCAS
Train Lighting System
Schematic Diagram.



AN ELECTRO-MAGNETIC REGULATING DEVICE.

Automatic regulators for maintaining constant voltage at a generator or feeding point in many cases are operated thru the use of electromagnets. These magnets operate when the voltage becomes too high or too low and close the circuit which sets in motion the regulating device proper, such as a resistance regulator, or storage battery cell switch. When normal voltage is reached the circuits of the regulators are opened by the release of the electromagnets. The electro-magnet is thus in a sense the key of the apparatus. Owing however to the necessary delicacy of these instruments to obtain fine regulation, they form the weak spot in the apparatus. The most common electro-magnetic device used is a solenoid, connected across the voltage to be regulated. In the hollow center of the solenoid is an iron core to which is attached a contact piece. This swings between two stationary contacts. The core is acted upon by two opposing forces, the magnetism of the solenoid winding, and a spring or counter weight, - and for a given voltage, tends to take up a given position. If one of these forces, is changed, say the current, (due to voltage change) the balance is found in a new position. As the forces tending to move the core become less as it approaches balance, the core must be stopped before reaching this position, if a contact is to be closed. This is also the objection to regulating the field resistance thru a solenoid operating over a set of resistance contacts. There is always a lag due to friction, in an opposite direction to the direction of rotation. Another difficulty is that the solenoid core moves

only a small distance and unless considerable power is used in the solenoid, only small power currents can be broken, the weak power of the solenoid preventing any multiplying devices. This same difficulty applies to the Deprez system, where the contact maker is operated by a coil in a permanent field, the coil working against a torsion spring. This system is unsatisfactory as shown by the many attempts to increase the strength by shunt windings, and the auxiliary devices used.

In contrast to these delicate mechanisms consider the ordinary electro-magnet as shown in Plate 3. This gives a good strong contact, but until recently seemed inapplicable to this use. In this type of electro-magnet, the armature is held back by a spiral spring against an adjustable screw. With the coil across the line to be regulated, an increase of the voltage will cause the core to pull on the armature. This may increase until the pull of the spring just balances the core pull, when there is no pressure on the screw. The slightest increase of current will cause the armature to be pulled to the pole, the strength of pull increasing as the distance decreases, giving a good strong pressure. From this position if the current is decreased, the pull decreases until at a certain value, the pull of the magnet and the spring are equal. Even the slightest diminution of current will then let the armature spring back into its former position giving a good pressure at the screw. The difference in voltage or current required at release and set is too great to allow a single magnet to be used for the two purposes in its different positions. Also, the use of two magnets,

one pulling in at too high, and the other releasing at too low a voltage is not applicable without an auxiliary device, as the armatures do not come back to their original position without a great change of voltage. For regulating use, the armatures must, by some means, be brought back to their original positions at almost the same voltage at which they leave. The following is the scheme used and it has been found to work very well. Plate 3 is a schematic diagram of the regulating device. M_1 and M_2 are the magnets which are connected in series with the resistance R_1 and R_2 across the points (+) (-) across which constant voltage is to be held. M_1 closes at too high a voltage and is called the maximum magnet while M_2 opens at too low a voltage and is called the minimum magnet. O_1 and O_2 are two coils which operate a solenoid or other mechanism to reduce (O_1) or raise (O_2) the voltage. The apparatus is shown in the position assumed at normal voltage. A_1 is released, leaving C_1D_1 open, while A_2 is drawn in, leaving C_2D_2 open. The armatures A_1 and A_2 are acted upon by the poles of the magnets M_1 and M_2 and the springs F_1 and F_2 working against each other so as to have a very slight resultant in the direction of their position. This adjustment is made in the rough by the adjustment of the spiral springs, the final adjustment being made by regulating the air gap, thru the adjustment screws S_1 and S_2 . The voltage at which M_1 draws in its armature is the upper limit to which the voltage may vary, while the voltage at which M_2 releases is the lower voltage. Thus it will be seen, the regulation can be adjusted as fine as desired.

The operation of the system is as follows. Starting at

normal voltage, we have the condition of apparatus shown in diagram. If now the voltage rises to the upper limit, A_1 is drawn in, closing $C_1 D_1$. This puts O_1 across the line and the mechanism for reducing the voltage is operated. This mechanism closes switch S_1 when normal voltage is reached. This short circuits the winding of M_1 , it loses its magnetism, and F_1 draws the armature back to normal position, breaking the circuit of O_1 , the operating mechanism which moves back to its original position opening S_1 . This leaves the apparatus in its original position, but the voltage has been reduced, and M_1 does not close.

If on the other hand, the voltage decreases to the lower limit, A_2 is released closing $C_2 D_2$. This puts O_2 across the line and the regulating mechanism operates to increase the voltage, closing S_2 at proper time. The closing of S_2 short circuits R_2 so that M_2 takes a heavier current causing it to pull in the armature A_2 , opening the circuit of O_2 . The regulating mechanism goes back, opening S_2 and putting M_2 again in series with R_2 , across the now normal voltage, which holds A_2 drawn in.

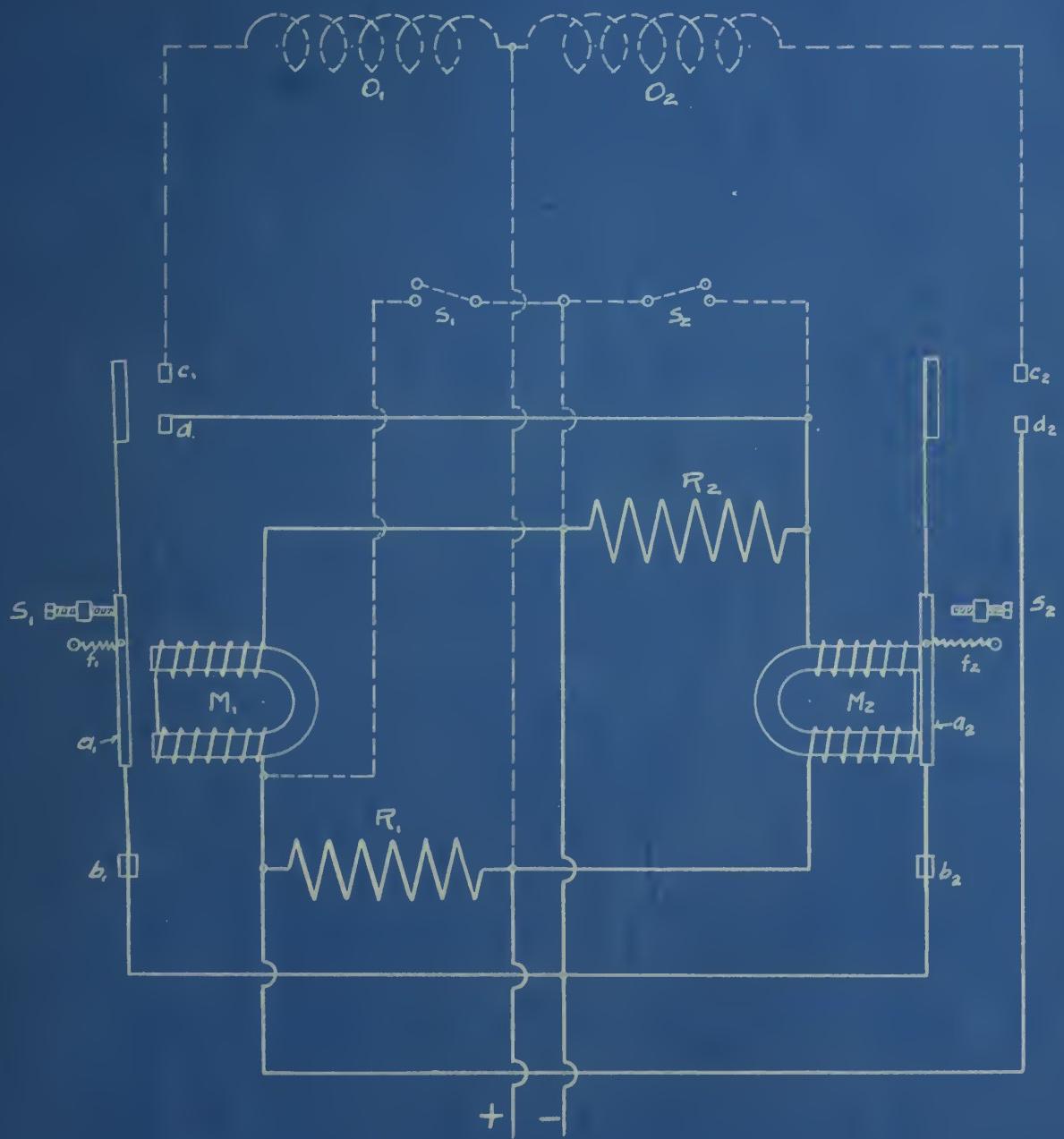
The contacts $D_1 D_2$ and their connections form a safety device. In the case of vibration or jar it might be possible for one of the armatures to leave its position while the other is out. But the contacts $D_1 D_2$ prevent this. For example, while A_1 is closed, the resistance R_2 is cut out, M_2 being directly across the line. This effectively prevents A_2 from leaving the drawn up position. When A_2 is released, (low voltage) A_1 is prevented from being

drawn in by the short circuiting of the windings of M_1 thru b_2 d_2

As to the degree of regulation which can be obtained from this device, it is readily seen, that the points at which M_1 and M_2 operate can be brought as near together as desired. However, the steps in the regulating mechanism are perfectly definite, and the total range ^{of} voltage which the magnets allow must be greater than the greatest step on the resistances. If this is not so, the voltage will fluctuate from too high to too low and vice versa, the magnets never coming to rest while this condition is maintained.

PLATE 3

ELECTRO-MAGNETIC
Regulating Device
of
Paul Thiemc
for
Regulating Exciting Field
of
Variable Speed Generator
to give
Constant Voltage.



THE BLISS CAR LIGHTING SYSTEM.

In the Bliss car lighting system, the generator voltage is regulated as usual by a device which reduces the field to compensate for the increase of speed of the generator and vice-versa. It differs from other systems in the method of accomplishing this. Another difference is the lamp bucker arrangement for keeping the voltage on the lamps constant, while the voltage on the battery may vary.

The schematic diagram on Plate 4 shows the arrangement of apparatus and connections. The main generator, which is driven from the car axle, has two windings C and D. The winding C, it will be noticed, is placed across the storage battery in series with a resistance R and a snap switch S_1 . The other winding D is a shunt field being connected across the terminals of the generator thru the armature of the field bucker B_f . The auxiliary machine consists of a motor M, which is direct connected to an armature, which has two windings B_f and B_l , these being respectively the field and lamp buckers. The motor is of the shunt type, with a series starting coil. One armature and one field (E) terminal are connected to the negative side of the generator, while the other armature terminal is connected to the field so as to make a few of the turns series. The other terminal of the field is connected to the plus side of the generator. The two armature windings of the bucker are connected together on the negative side of the generator. The plus end of the B_f is in series with the field of the generator while the plus terminal of B_l is connected to the lamps.

The field of the bucker is of a shunt nature, being connected across the generator in series with a resistance O and in parallel with H , when contact M is open. The regulating device shown above the generator has two windings A and H . They work together and are of such character that when the generator reaches normal voltage, the current which flows thru them in series is just enough to lift the armature $K-J$. The Reed regulator L is connected across the lamps when J is up, and at normal voltage and above, holds the magnet armature down, keeping contact at M open.

The operation of the system is as follows. At standstill, the generator generates no E.M.F., consequently no current flows thru A and H and the magnet armature is down, closing contacts at K and opening them at J . Magnet L , which is in series with resistance T across the lamps, has its circuit opened at J , therefore contact at M will be closed. Thus, when the lamp switch S is closed, it is seen, that the lamps are connected across the storage battery thru S_1 and contact K in parallel with B_1 . The closing of contact M of the Reed regulator has short circuited the field of the bucker, so when ^{the} generator armature revolves, the winding D , being shunted across its terminals thru resistance of B_F , by aid of the residual magnetism rapidly builds up the voltage. In case there is no residual magnetism, the switch S_1 is closed. This puts the exciter winding C across the battery terminals in series with R , and the generator builds up with certainty. The exciter winding may be used merely for starting, or may be left connected while generator is running. Its effect is small and when the battery is

being charged it acts as a weak winding, whose ampere turns act in same direction as the other winding. The motor M begins to work as the generator voltage picks up, but as the bucker field is short-circuited thru M_1 , there is no bucking effect on either the lamps or the generator field.

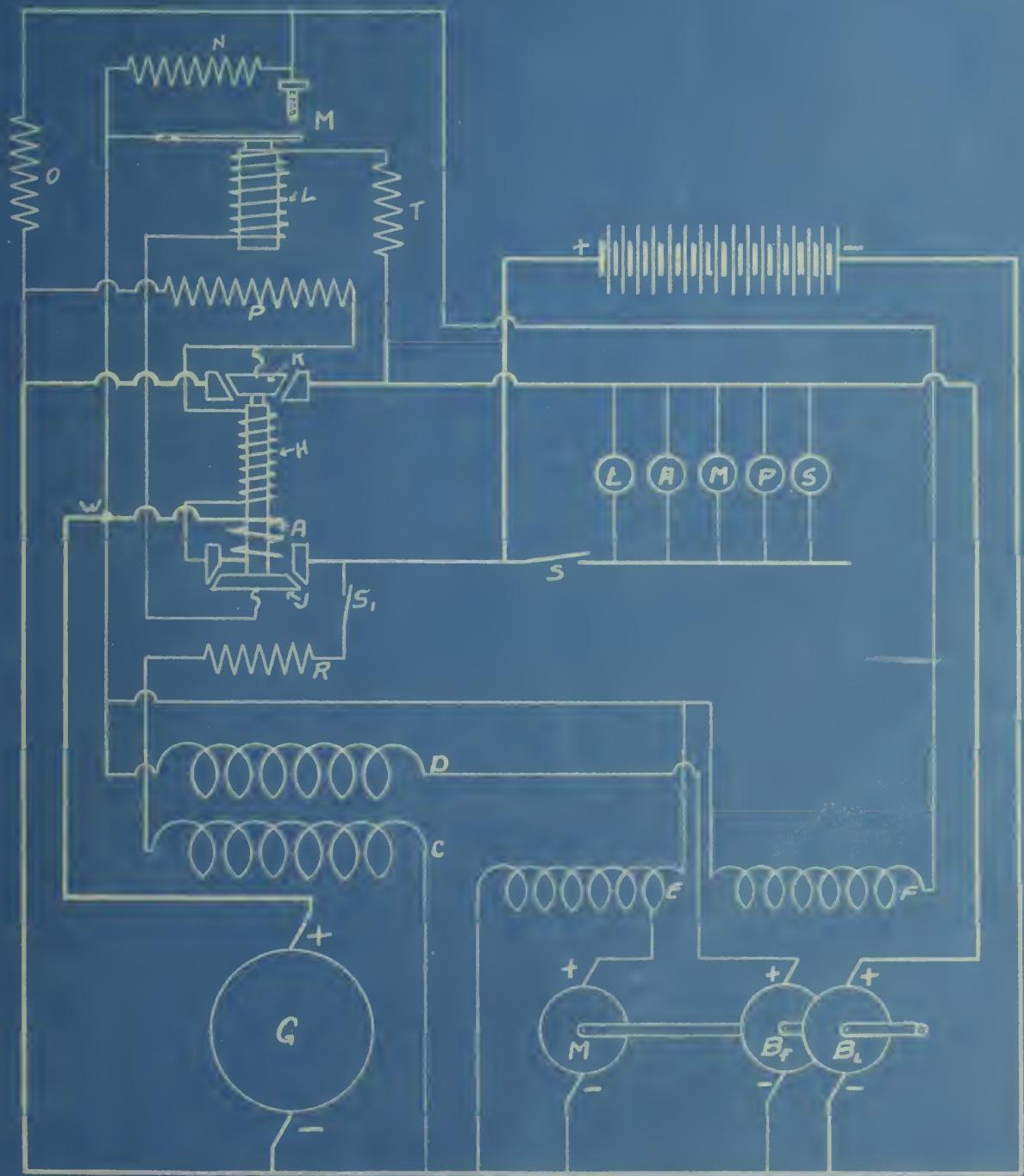
When the generator has built up to slightly above no load battery voltage, the current flowing from W thru A, H, K to G, causes the magnet to pick up, breaking contacts at K and closing them at J. The breaking of contact K makes the current of H pass thru the resistance P, decreasing it (the current), and the magnet would tend to fall. But considerable less magnetism is required to hold the magnet up than is required to draw it up, and in addition there is an increased current flowing thru A. The resistances of P_1 and H are so proportioned that the magnet drops when the voltage of the generator falls below the point where the magnet picks up. The closing of J now puts the battery and lamps in parallel across the generator. The battery is directly across, while the lamps are in series with the lamp bucker B_1 . The closing of J also closes the circuit of magnet L which now being across the lamps, at higher voltage, at once draws in its magnet breaking the contact at M and energizing the field of the bucker. This at once causes the lamp voltage to drop down, as well as to reduce the generator field and consequently the voltage. As the bucker is already running at full speed, the action is almost instantaneous and the lamps are not across the higher generator voltage long enough to cause more than a flare, when the system changes over to normal running.

position. Now any tendency to increase voltage, due to say an increase in speed, will be met by faster rotation of motor M and consequently increased bucking effect on both generator field and lamp voltage. The bucking effect increases not only with the motor speed but also with the actual generator voltage, as the bucker field is connected across the line. If now, for some reason, the voltage across the lights drops below normal, the magnet L releases the armature, closing the contact at M. This short-circuits the bucker field, and the voltage of both generator and lamps rises. When the voltage of the lamps again reaches normal value the magnet L opens contact M, and the operation continues as before. Magnet M does not release until the voltage has dropped considerably below the point where it pulls in. In actual practice, this action seldom takes place, for, when the lamp voltage drops it is generally due to dropping generator voltage, which in turn is due to the decreased generator speed. This decrease in generator voltage causes a decrease in battery current, and when the battery current has become very low, the other regulating device drops its armature, opening the circuit of L, and the generator at J, and putting the lamps across the battery at K. This condition is maintained until generator speeds up again to the lower speed at which generator operates.

The great advantage of this system is that the battery can be charged by a high voltage while the lamps are running on normal voltage. The battery may be used for other purposes and may be charged from the generator without using the lights at all.

The fault with this device is, that should an open occur in either the lamp circuit or the circuit containing the magnet M, there would be no bucking action, due to the short circuited field. This would cause the generator to generate a dangerously high voltage, as well as to have a detrimental effect on the battery. If the failure were not in the lamp circuit, the high voltage would ruin the lamps. This danger may be avoided by properly fusing both the lamps and the battery circuits, as well as the generator.

BLISS ELECTRIC
CAR LIGHTING CO'S.
Constant Potential Equipment.
Theoretical Wiring Diagram.



THE ROSENBERG GENERATOR.

The Rosenberg generator is the outcome of a demand for a simple train lighting generator. The development started from an idea originated by H. Rosenberg of Wien. This idea was to have an ordinary generator A whose field was supplied by an exciter mounted on the same shaft. The field of the exciter was differential wound, the predominating coil being connected to a source of constant E.M.F. such as a storage battery, while the differential field was connected in series with the armature of the main generator A. This apparatus worked very well, the generator giving unidirectional current regardless of the direction of rotation. The question was to get these results in a simplified machine if possible. The study of this problem which at first seemed unsolvable brought to mind a machine of Deni which had two sets of poles, one superimposed on the other while the armature had two separate windings. This latter was to be eliminated if possible as for railway work especially the simpler the device the better. Some experimenting at the shops of the Allgemeine Electricitts Gesellschaft finally produced a machine which utilized the cross flux of the armature, instead of another winding, to gain the desired result.

In an ordinary generator, the armature current produces a field that is at right angles to the original field. This distorts the field and is guarded against either by preventive windings or by suitable designs. But in this new machine this cross flux plays a highly important part. Figure 1 shows a machine having all the parts of a regular two pole generator, even though they are some-

what distorted. In addition there are two extra brushes b-b', while the other pair a-a' is short circuited.

It is a common thing where large generators are to be tested and insufficient power is at hand, to short circuit the armature and weaken the field so much that at normal speed only full load will flow in the armature. This field excitation is very low when compared to normal voltage excitation. For a machine designed to run equally well in either direction, the brushes, set at the mechanical neutral should not spark under this test. An analysis of the various fields of such a machine yields the following. The original field, whose lines of force pass say upward, may at normal speed be very small, being only enough to induce the RI drop in the armature and brushes. Let this be OI figure 2. The armature current causes a cross flux which is much larger than the original field and 90 degrees from it say II. It is a common thing in a generator to have the leading pole tip weakened while the other is strengthened due to this cross magnetizing effect of the armature current. This shows that the relative direction of the flux is as shown in O II in figure 2 and 3, the direction of the armature flux reversing with the direction of rotation. This flux combines with the original field flux to give a certain resultant, but for the purpose of this discussion the flux will be treated in its components. Thus it is seen that we have, superimposed over the original field another, which is much stronger and whose axis is at right angles to the original being 90 degrees ahead in the direction of rotation. This fluxes are shown as O II in figure 2 and 3, OI being the original field flux.

If now two brushes b-b' are placed with their axis at right angles to the axis of this armature flux, there will be a difference of potential between them, due to the armature conductors cutting the lines of force of the cross field Φ_{II} . This difference of potential will be in the same direction, regardless of direction of rotation as with a change of rotation, both the rotation and the direction of the flux Φ_{II} is changed, the result being that the E.M.F. remains in the same direction. If the circuit across b-b' is closed thru an external resistance, a current will flow thru the armature. This of course will cause a cross field which is 90 degrees ahead of the inducing flux in the direction of rotation, (Φ_3 figure 4) which places it 180 degrees ahead of, or in direct opposition to the original field flux Φ_1 . If the principal current, (thru b-b') is greater than the auxiliary current which flows thru the short-circuited brushes a-a', the ampere turns Φ_3 will be greater than those of Φ_2 . In order that we may have the proper armature current to build up properly it is necessary to increase the number of ampere turns of the original magnet system by a value of Φ_3 making a total of Φ_n equals $\Phi_3 + \Phi_1$. The combined fluxes Φ_n and Φ_3 leave the proper value of Φ , for reducing the auxiliary armature current. In an ordinary machine, this increased excitation would be obtained by a series winding, which would for each value of load, compensate for the bucking force Φ_3 . But for machines which have to operate in parallel with a battery, and especially those machines which are axle driven, the best method is to supply the field with a suitable winding that will

give the necessary ampere turns at the required load.

This is of considerable importance as it affects the performance of the machine considerably. To give an idea of some of the relative values of this machine, it may be said that at normal speed the ampere turns necessary to develop the primary field are 10% of those necessary to compensate for the "secondary" armature reaction Φ_3 . This means that the field windings carry only 10% more A.T. than that necessary to compensate for reaction of Φ_3 . Under the same conditions, the current flowing between the short-circuited brushes a-a' is 40% of the load current flowing thru b-b'.

The operation may be described as follows. Running at normal speed, the relations are as shown. Now every increase in working current, thru armature reaction weakens the total field Φ , weakening also the current between the auxiliary brushes a-a' and therefor the cross flux. This will cause the voltage to fall off, until the current has again reached normal. If speed is increased to say double the normal, it is clear that the working current can never rise to more than possibly 10% above normal, for if it had risen to this value, the value of Φ_n and Φ_3 would have been equal and there would have been no primary exciting field Φ_1 . No matter how high the speed increased, the current in the main circuit could never overstep this maximum value. Suppose on the other hand, the speed is decreased to say 70% so that the working current has a tendency to decrease. If for this reason the working current were to drop off 10%, the value of Φ_3 would be 10% less, while the resultant primary flux Φ , would be doubled. This flux in spite of

the decreased speed would cause a current of 40% larger to flow in the auxiliary circuit causing the secondary field to increase almost as fast as the speed decreased, holding the voltage and current almost constant. This shows that at constant voltage, the speed can be reduced to a very low value before the load current disappears, as there is an extraordinary large reserve of compensating ampere turns which can be drawn upon to make up for the decrease in speed, by strengthening the secondary field. The principle of the regulation lies in the fact that the exciting field is the difference between two almost equal fields. A small percentage change in either of these produces a large percentage in their difference. This supplies a reserve which can be automatically drawn upon to compensate for any change in speed. An ammeter or voltmeter connected to the external resistance of this machine appears as almost nailed, while the speed of the machine is varied from the highest down to the very lowest speeds, especially when the machine is operated so the voltage is low. The ammeter as in the case of the short-circuited A.C. generator, sinks fast only as the machine approached standstill.

This machine then, regulates for constant current. If we have a constant value of resistance in the circuit we also have a constant voltage at all excepting extremely low speeds. If a storage battery is on the circuit, the voltage regulates itself to allow for the number of cells and the condition of charging of the battery (counter E.M.F.).

The relation between speed and current, with a storage

battery for load is shown in figure 5. Taking the top curve, which corresponds to the strongest excitation it is seen that at about 340 R.P.M. the generator voltage has built up to battery voltage. From here the current picks up fast. At 700 R.P.M. it has gone beyond the knee of the curve and from here on approaches a given horizontal line asymptotically. From 800 to 2400 the current change is about 12% while from 1200 to 2400, a hundred percent change of speed, the current change is about 1%. If the excitation is decreased we obtain successively the other two curves shown in figure 5. It will be noted that as the excitation is decreased, the machine builds up more slowly and the battery voltage is reached only at a higher speed. However, the knee of the curve is passed and current becomes almost constant sooner at the lower values of excitation. The current flowing is in fact almost proportional to the exciting current. By adjusting the latter the current output of the machine can readily be adjusted.

The curve plotted between current and speed with resistance in the external circuit (figure 6) goes of course thru the origin. However up to 600 or 700 R.P.M. it is very much like the curve shown in figure 5. With a load of carbon lamps, the curve runs even better, as the practically horizontally part commences at a lower speed.

Figure 1 shows the machine as it is connected up in the trains of the Prussian Government. The brushes a-a' are merely short-circuited. The main brushes b-b' carry the load. The field it is noticed is connected across the battery. This ensures

building up in the right direction, but even without the storage battery the machine will build up as a shunt generator, if fields are connected across brushes b-b'. In the connections shown, the storage battery, and lamps with resistance are connected in parallel. The arrow like notation in the line from brushes b to the battery represents an aluminium cell. This cell allows current to flow in direction of arrows, but prevents current from flowing in opposite direction. This is necessary as when generator slows up and voltage decreases, the battery would otherwise tend to run the generator as a motor.

As lamps are to burn at same voltage when battery is operating as when running on generator, a resistance of high temperature coefficient is inserted in series with the lamps. This allows the generator voltage to go high enough to charge the battery, while the slight increase in current causes resistance of r to increase so that the current thru lamps when generator is running is only slightly more than when the lamps are running off the battery. In an exhibition test, the voltage of battery at charging was 20 volts higher than at discharging but no change of intensity was noticeable at the lamps. That this machine will satisfactorily perform a variety of functions has been shown, and owing to its simplicity it is especially adaptable to train lighting work. But a few other things such as its size compared with other machines of equal output, and heating must be considered while the position of the brushes and the varied nature of the fields would at once raise the question of commutation.

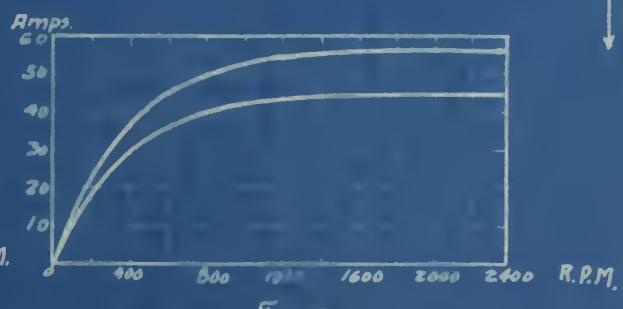
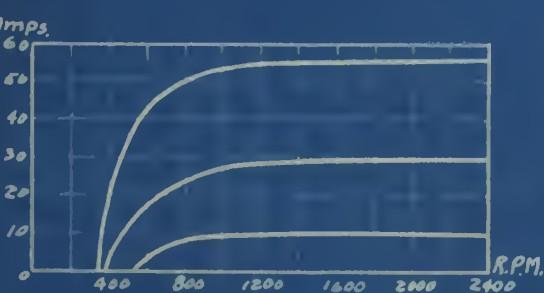
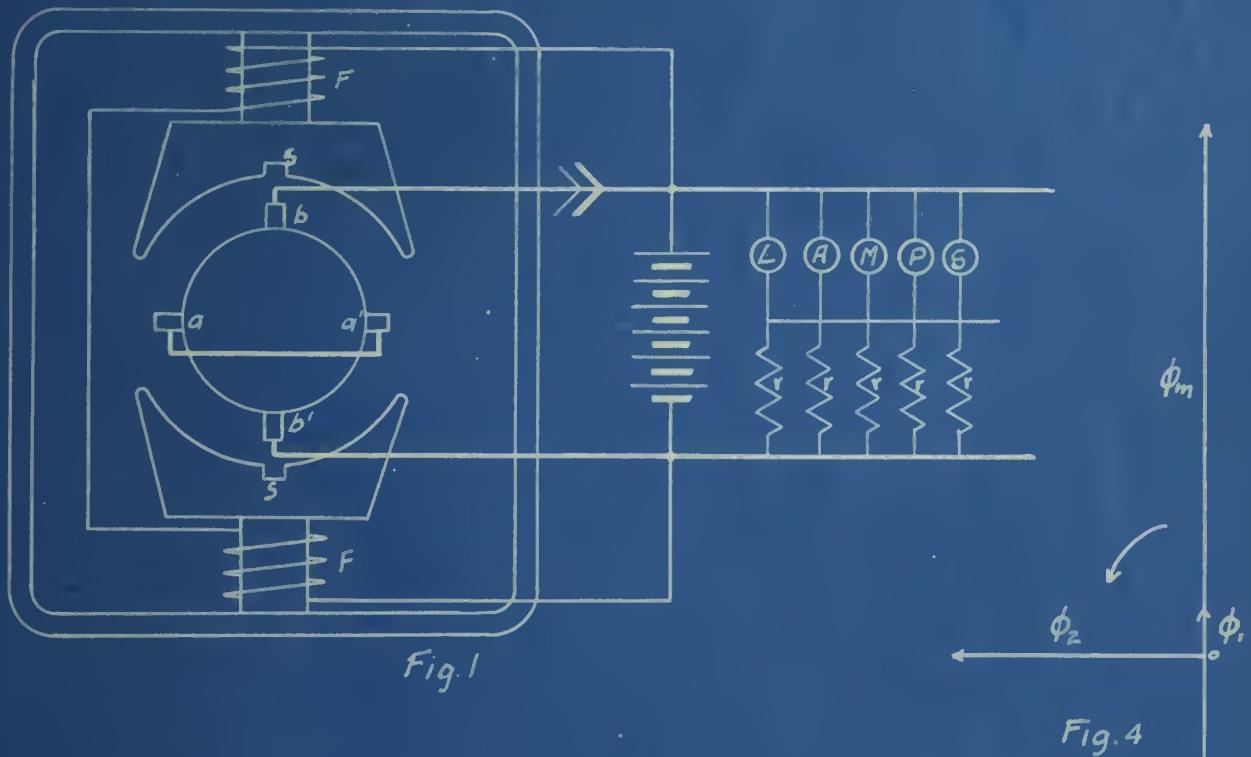
In the armature there are two currents, the load and the auxiliary or short circuit current. This latter is about 40% as much as the former. This at first sight would suggest an armature designed for 1.4 full load current. But these currents in the armature are at right angles and their sum is the hypotenuse of a right triangle of which they form the sides. This gives us a value of 1.075 i.e. the armature should be designed for a current of 7.5% larger than the output of the machine. If the machine runs a long time at low speeds, the short-circuit current must be high and in this case more allowance should be made in the use of copper. With this provision made, the heating would be the same as in an ordinary machine. Owing to the double number of brushes, some foresight should be used in the design. But ^{on} the other hand, there are great savings in the magnetic circuit. The main field is developed in the armature, the path being thru the pole-shoes back to the armature. Only the pole-shoes must be designed for this flux. Only a small flux Φ_1 goes thru the field core and the yoke. This permits these parts to be made extra small and has in addition the advantage that owing to the smaller core the mean length of turns is less. As the field winding develops only 10% more flux than the armature reaction, the current and therefor the cross section of field conductors can be made smaller.

This leaves the question of commutation to be settled. Taking up first the auxiliary brushes a-a'. These operate under far better conditions than the brushes of a normal machine. The current which is collected is only 40% normal which would be a

great advantage as far as brush heating is concerned. As the speed increases the short circuit of a-a' decreases, while the friction loss increases. The sum of the two losses is almost constant. The main brushes however are in middle of the pole-shoe. In an ordinary machine this would be a bad position, but in this case the flux Φ_1 which is being ^{cut} by the armature is very weak. The total E.M.F. induced by Φ_1 in all the armature coils is only enough to make up for the RI drop of the short circuited armature, and this where I is only 40% of full load current. The E.M.F. of a single coil, when short circuited in the worst position would hardly be enough to cause more than full load current to flow. To allow however for failure to get the brush on the mechanical neutral, a slot is cut in the pole face at the point of commutation. In actual operating conditions, the machines have been found to be absolutely sparkless.

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THE ROSENBERG GENERATOR
as used in
Train Lighting System
of the
Allgemeine Elektricitäts Gesellschaft.



A MOTOR - BUCKER REGULATING DEVICE.

This device is one which has been proposed, by a prominent electrical engineer, for holding the voltage on the lights constant on interurban cars. The connections are shown on Plate-6. M is a motor with a series winding A. This is direct connected to a generator G with another series winding B. The generator is connected in series with the lamps, thru the magnet C. It will be seen that the current for both motor and generator is taken thru the field A of the motor. The generator G is connected up as a bucker or "debooster". The current of the motor armature normally passes thru the field of the "debooster". The theoretical operation is as follows. With normal voltage, current passes thru A and divides at F, part going thru M to H; B and to ground, while the remainder goes thru the "debooster" G thru C and the lamps to ground. The current ⁱⁿ the motor M, sets it in motion and a bucking action is set up at G. It will be noted that, although designed for 550 volts, only four ^{lamps} are connected in series. The "debooster" G should, at 550 volts on line, generate a counter E.M.F. of 110 volts, leaving 440 volts across the lamps. This disregards the small drop thru A and C. If now the voltage increases, the motor M takes more current, causing it to speed up. At the same time, the increased motor current passing thru B causes the field of the "debooster" to be strengthened. These two forces acting together increase the counter E.M.F. of the "debooster", thus making up for the increased voltage across the "debooster" and the lamps, keeping the voltage on the lamps con-

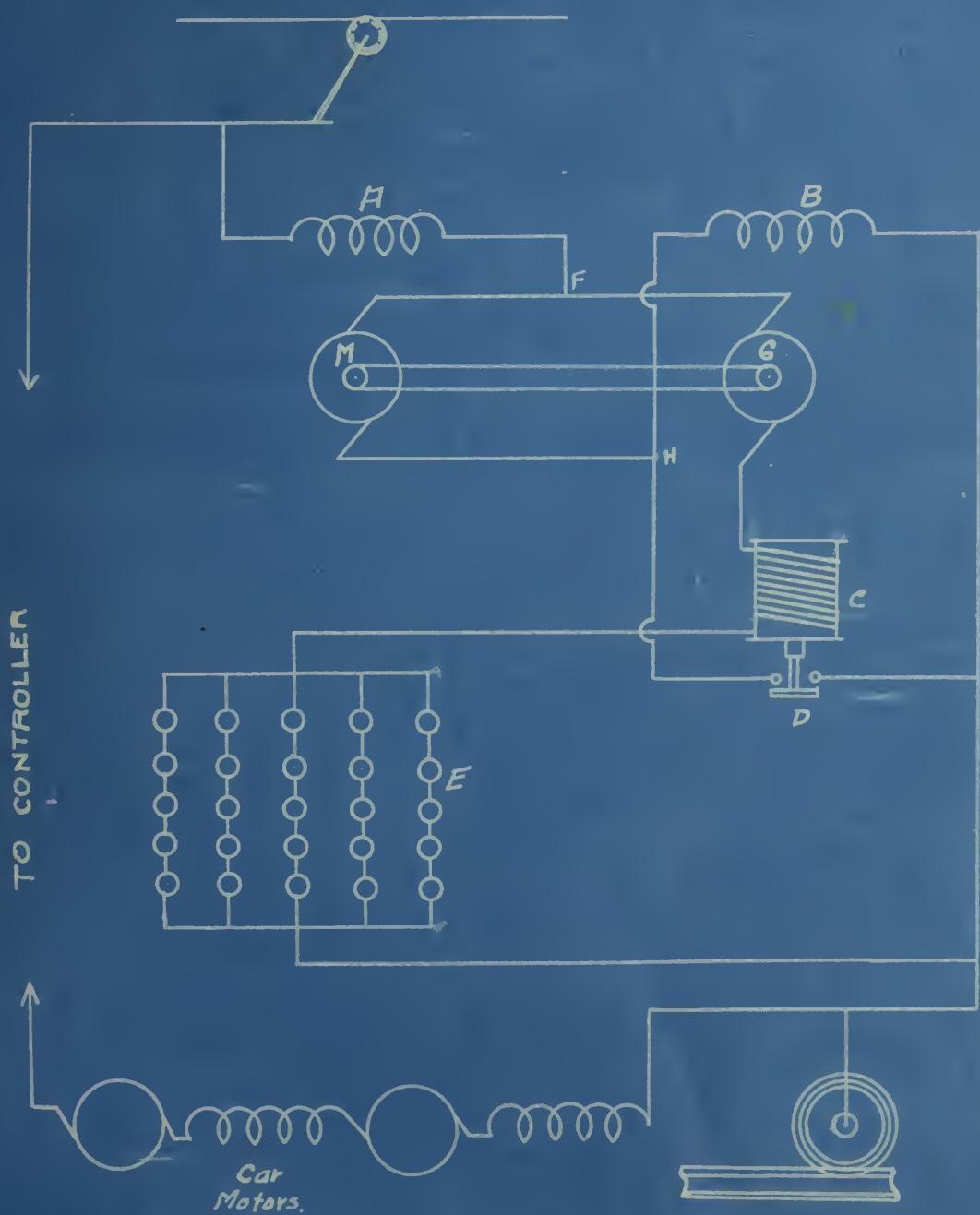
stant. If on the other hand, the voltage decreased, the current thru the motor decreases as well as its speed. This causes both field and speed of the "debooster" to decrease, and the voltage across the lamps is still kept constant.

The operation of the magnet C seems to be reversed. If the current thru the lamps becomes too high, the magnet C will close the contact D, short-circuiting the field B of the "debooster." This will put the lamps almost across the dangerously high voltage line, which is sure to burn up the lamps. The magnet C is sometimes placed across the lamps, in which case it operates when the voltage across the lamps becomes too high.

A test made with this system gave very poor results. The accompanying graph Plate-7 shows the relation between the applied voltage and the voltage across the lamps. The lines of each test if continued would pass thru or near zero. As they are straight lines, it follows that the same percentage variation was obtained across the lamps as across the entire circuit. The inability to get results is perhaps due more to the inadequacy of apparatus, than any thing else, as one of the machines (the debooster) was a compound wound machine whose series windings consisted of only a few turns. It was thought by increasing the number of lamps, the effective ampere turns and therefor the deboosting capacity of this machine would be improved. The difference is shown in curves 2 and 4, 4 being the more heavily loaded one. Just to see to what extent the debooster was acting, its field connection was reversed, so as to boost the voltage on the lamps. The data obtained here

is shown in curves 1 and 3, these corresponding respectively to 2 and 4, that is, the number of lamps in 1 and 2 were the same. 3 and 4 were also run with the same number of lamps. The slight difference of lamp voltage shows approximately two times the deboosting effect of the generator. With suitable designed apparatus this system should give a pretty good regulation. It has the one great advantage of being electrically automatic.

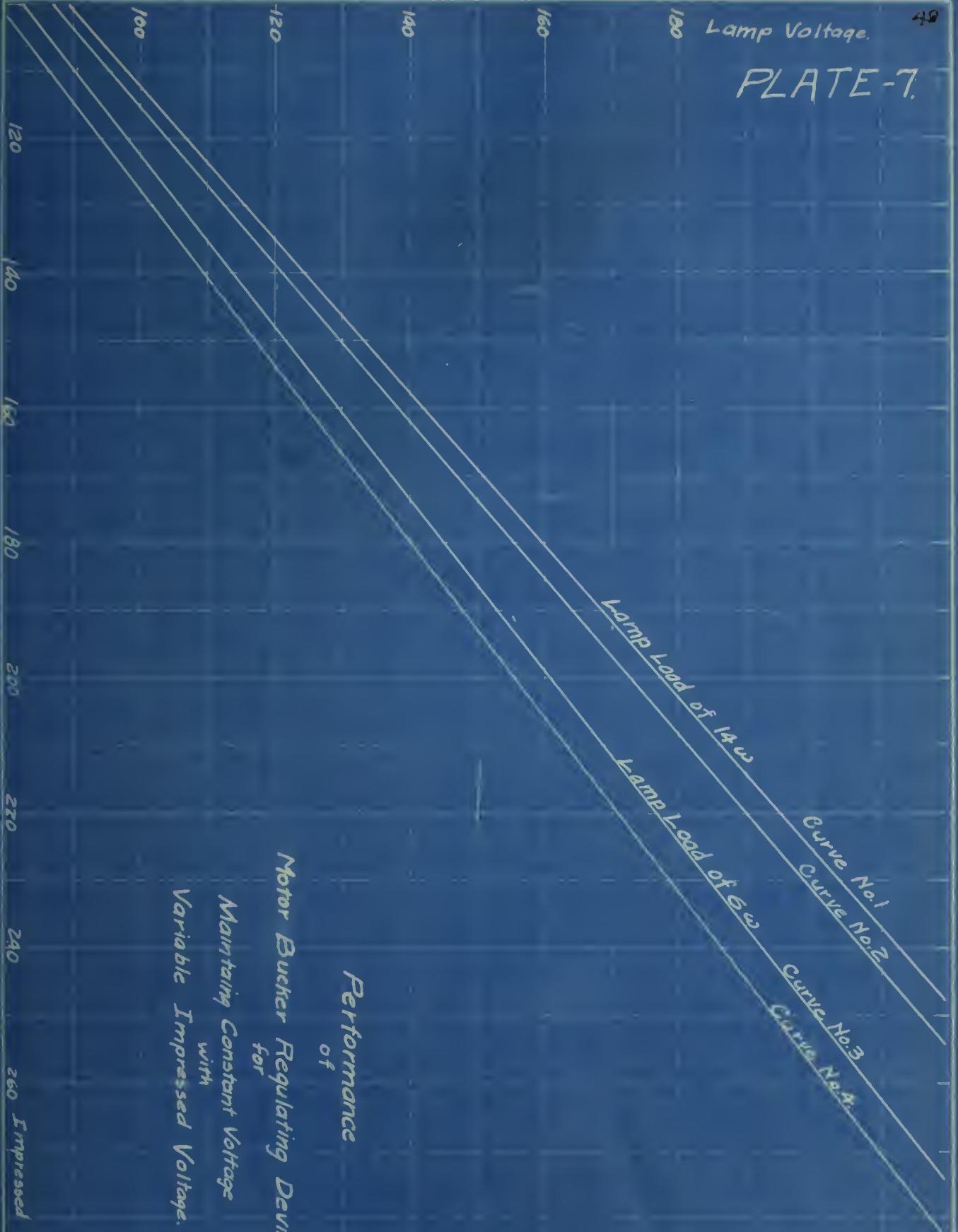
MOTOR-BUCKER
REGULATING DEVICE
FOR
REGULATING VOLTAGE OF LIGHTS
ON
550 VOLTS D.C. LINE



Lamp Voltage.

PLATE-7.

Performance
of
Motor Bucker Regulating Device
for
Maintaining Constant Voltage
with
Variable Impressed Voltage.



LOPPE'S SYSTEM OF TRAIN LIGHTING.*

The principle of this system is as follows:- The generator which is driven at variable speed from the axle is provided with a constant excitation from the storage battery that is necessary for supplying current to the lights when the car is standing still. In opposition to this constant excitation is a shunt excitation which varies directly with the voltage of the generator. The interaction of the two fields tends to keep the terminal voltage of the generator constant. For, if the speed of the generator increases, the generated voltage will tend to increase but will increase the differential shunt excitation and hence decrease the resultant flux and consequently the generated E.M.F.

The shunt excitation can never equal the excitation due to the constant current for its source is the voltage produced by this constant excitation.

It is evident that the voltage will always increase slightly with the speed for it is only by increase of voltage that the shunt excitation is increased and the resultant flux decreased. It is also evident that the stronger the shunt field is made the better will be the regulation, for then a slight difference in voltage will produce a large difference in the resultant excitation.

The scheme was tested out using a compound generator. The series field of this generator was put in series with a lamp bank across constant voltage mains, while the shunt field was connected to the terminals of the generator. The series field was predomina-

* Electrical World and Engineer December 20, 1902

ting at all times, while the shunt was bucking.

In the first case at a given speed, the series (constant) field induced 32 volts in the armature while the shunt (variable) field built up to 26 volts at the same speed. When the shunt field was connected in opposition to the constant field, the voltage built up to 15 volts at a speed of 980 R.P.M. The speed was raised to 1450 R.P.M. and the terminal voltage of the machine rose to 18.5 volts. This gave an increase of voltage of 23.3% for an increase of 48% in speed. On the second test, the constant field alone developed 50 volts while the shunt field alone built up 160 volts at the same speed. When connected differentially, with the constant field predominating, the machine built up to 19 volts at a speed of 955 R.P.M. An increase of speed to 1470 R.P.M. caused the voltage to rise to only 21.5 volts. This gives an increase of 13.3% in voltage for a change of 54% in speed. It is evident from the results of this test, that the stronger the shunt field in respect to the resultant field, the smaller will be the change of voltage for a change of speed in the resultant field. This is due to the fact that where the turns of the shunt field are very large, a small percent change in voltage will cause a large percent change in the resultant field. In this respect it resembles the Rosenberg generator, which also has two opposing fields. Thus for example, if the shunt excitation at a given voltage is ten times the resultant excitation, a change of one percent in terminal voltage causes a change of 10 percent in the resultant excitation which will allow a ten percent change of speed. On this principle, it will be seen,

that the voltage regulation of the machine can be made as small as desired by making the ratio between shunt excitation and resultant excitation as large as necessary. The Rosenberg generator regulates for constant current, while this scheme regulates for constant voltage. A scheme for using the former system is described on page 35.

A scheme like the above which is in actual operation is the Loppe system shown on Plate 8. The scheme is essentially as described above. The switches I are merely used to change the connections of the storage batteries. It is necessary to have two storage batteries in this case, one charging while the other is discharging. In the lower figure on Plate 8, a motor generator set is used to furnish the constant excitation for the generator, the motor being driven by the battery. This eliminates the necessity of having two storage batteries.

A FRENCH SYSTEM
OF
TRAIN LIGHTING
BY
Mr. F.M. Loppe

Fig. I. First Combination

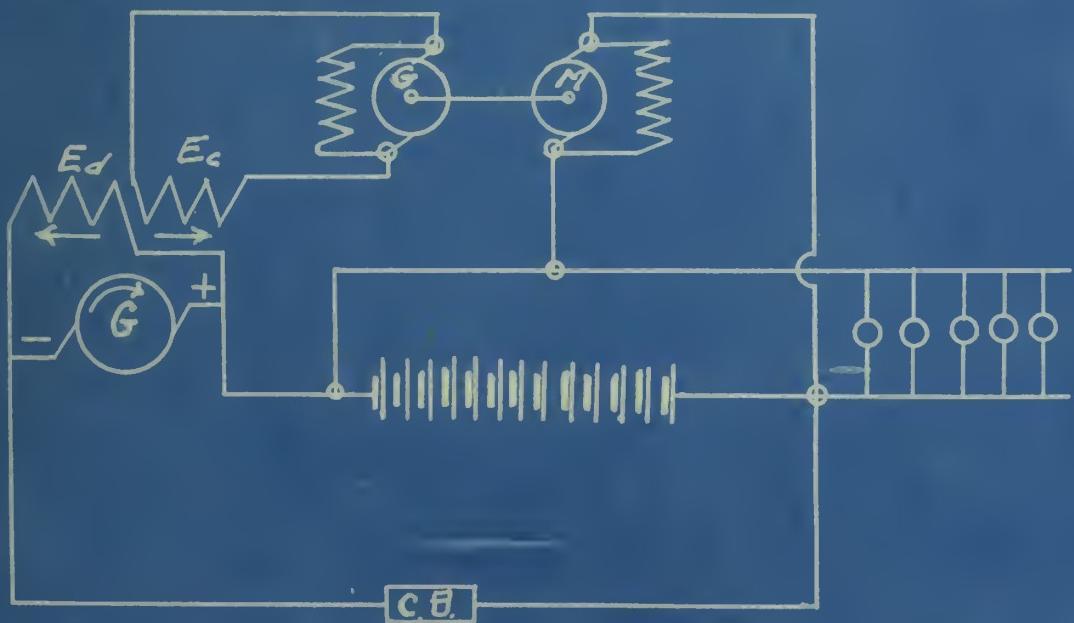
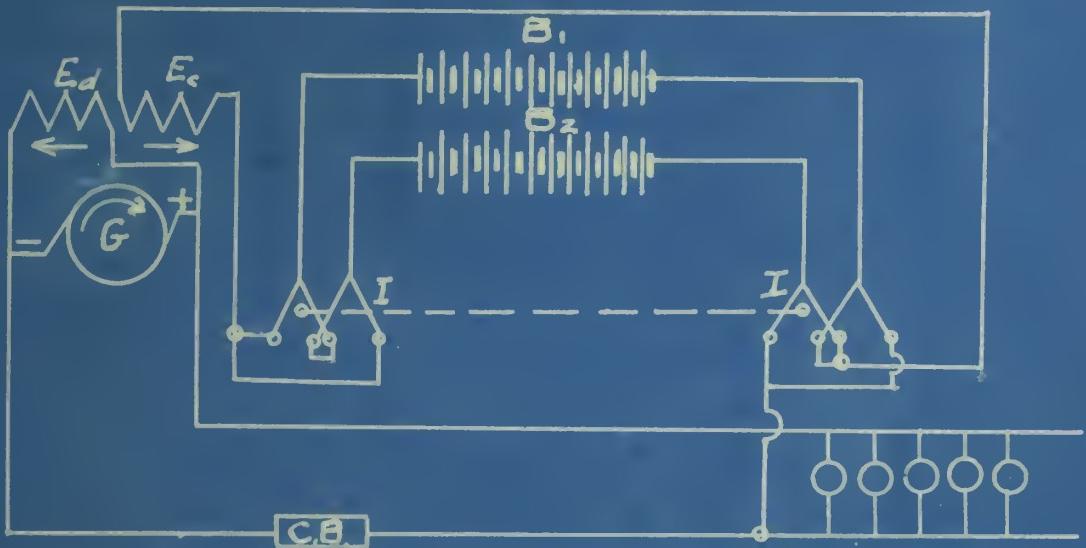


Fig. II. Second Combination

ANALYSIS OF ELECTRIC CAR LIGHTING PROBLEMS.

In the preceeding pages descriptions of existing train lighting systems have been shown and explained. Any one of these systems could be installed on an interurban car and would give excellent results. But electric cars are already furnished with a simple and cheap system, that under ordinary running conditions gives fairly good satisfaction. It is only on starting the car or cars on the line, that the present system fails. These periods are not long, and it is for this reason that operating officials do not install the expensive but otherwise satisfactory systems used on the steam roads. In the steam roads the prime mover for the power is shut down at more or less frequent intervals. This immediately necessitates the adoption of some apparatus for storing energy while the car is running, to be used up when the car is standing still. The only practical solution for this difficulty has been found in the storage battery. But in the electric car, we have always a source of power whether the car is standing or running. This immediately eliminates the necessity for a storage battery and suggests a simplification of the total apparatus. But the power on a steam car, while varying between wider limits than that on an electric car, varies more slowly. This slow change of power gives the complicated regulating devices plenty of time to act. This applies especially to systems where the regulation is obtained thru a rheostat with movable parts and to those devices using resistances of high temperature coefficient. In the electric car, the fluctuations, while

varying only between say 300 and 550 at maximum, may run over the whole range instantaneously and then perhaps right back again to where it started from. This at once eliminates most of the railway schemes used at present, as most of these require an appreciable time for any change of power to adjust itself. A closer inspection of the voltage variation and an analysis of other features of car operation with respect to lighting reveals the following.

Assuming that a single car is on the feeder of the sub-station.

Then when the car is standing, there is a very small drop over the line, due to the current for the lights. This makes the car voltage almost as high as the station voltage. If 5-110 volt lamps are connected in series across the line, which is usually the case, the lamps will develop their full rated candle power. If now the car starts, it draws a current of from three to four times the value used when running at full speed. This current falls off and increases as each step of the controller is reached and passed, but the variation is not very great. The large motor current now flowing over the line from the sub-station, causes the voltage to drop off. The amount of this dropping off depends upon the size of motors and upon the length and arrangement of feeders. With two cars starting at once, the voltage may drop to below 300 volts. However under ordinary conditions with a single car starting midway between sub-stations, the voltage will not drop much below 400 volts. This causes the lights to fall to a very low value. When the starting resistance has all been cut out, the current begins to decrease causing the line drop to decrease and the

voltage at the lamps picks up. At ordinary running condition the line drop is sufficient to make the lamps burn far below their rated candle power. If now the motor current is turned off the line drop becomes negligible and the lamps flare up, dropping again when the power is again turned on. The voltage equation of a lamp is $C.P. = E^x$ where x varies from 3.4 in tungsten to 6 in carbon lamps. This shows that any change in voltage causes a much larger percent of change in the strength of the lights. This effect is so great, that even when the car is running, the increased drop due to the compressor motor starting up causes a visible drop in the candle power of the lamps.

Any device used for regulating the voltage must then fulfill the following conditions. (1) It must be cheap. (2) It should be light and compact. (3) Require little attention. (4) Have the ability to regulate properly for sudden changes. (5) It is desirable to have it work properly on two different loads.

Number 4 makes it almost impossible to use any device using movable parts (not rotating) and is together with (1) the dominating factor. It is almost impossible to get regulating devices without moving parts for D.C. work. The motor generator set subsequently described offers one solution, while the only scheme which has absolutely no moving parts is the resistance with high temperature coefficient. The use of a solenoid actuated carbon-pile is also discussed in the succeeding pages. The use of air for operating a rheostat, having the air valves electrically operated, was given up after an investigation showed the difficulties were too great.

A MOTOR GENERATOR CAR LIGHTING SCHEME
USING THE ROSENBERG GENERATOR.

The great flexibility, adaptability and simplicity of the Rosenberg generator together with its almost ideal characteristics for the purpose, suggests the solution of the electric car lighting problem. At first sight two methods appear for the use of the generator. One is to drive the generator with a motor, the total lighting load being taken care of. The other scheme is to use the generator as a booster. The advantage gained in doing the latter is that smaller machines, both motor and generator could be used. For example if voltages between 300 and 550 are to be taken care of the machines could be about $\frac{3}{5}$ as large as when used as straight motor generator set. There are however several objections. The generator would probably hold the current constant if connected across a trolley line in series with the lamps, if it acted as a booster. But the generator holds constant current when the field excitation is conatant. This latter would be rather diffcult to get on a car, the best place being perhaps across the regulated lamps. There would also be a lower limit beyond which the machine would not work properly. With this system no saving could be made, or at least but little saving could be made in the operation of the headlight, as no low voltage is available. The single arc takes more current than all the incandescent lamps together and putting it in series with lamps and resistance would either involve a complicated system of switches or else the headlight and lamps would all have to burn at the same time. In either case there would

be considerable rheostatic loss.

In the motor generator set, we do away with many of the disadvantages while we incur only one disadvantage, namely, increased first cost. Take for example a car having 35 incandescent lights and a single arc headlight taking 5 amperes at 80 volts. Under the present system, if the lamps were burned at their full candle power we would have a considerable saving. At present 55-watt carbon lamps are used, while the headlight is connected in series with enough resistance to cut down the voltage to 80 volts. The total power then is $35 \times 55 + 5 \times 500 = 4425$ watts. Under the proposed system owing to the low voltage, tungsten 1-1/4 w/c.p. could be used. Taking 20 instead of 16 c.p. lamps we have for an 80 volt system the following estimate. $35 \times 20 \times 1.25 + 5 \times 80 = 1275$. Assuming an efficiency overall of 70% for the machines this makes power input equal 1820 watts. This effects a saving of 2605 watts which at a basis of 1200 light hours a year and power at .5¢ per K.W.H. gives a power saving of \$15.6 per year. This capitalized at 10% for interest and depreciation would warrant an expenditure pf about \$156 for the new apparatus. The tungsten lamp is becoming more and more successful in railway work. The old arc headlight is now being replaced by the tungsten 300 to 400 watt light. In this system it is immaterial which of the two headlights is used.

With a watt output of 1275 at 80 volts, the generator would have to furnish a current of 16 amperes. The motor, operating on 500 volts would have a higher rating. The system suggested is shown diagrammatically on Plate-9. The motor M is direct connected to the Rosenberg generator G.

The Resistances R_1 and R_2 are placed in parallel, in series with the field of the generator. The relay A is connected in the head-light circuit, while both lamps and headlight circuits are connected thru their respective switches to the terminals of the generator. The auto-starter is connected in series with the armature of the motor, which is driven from the trolley voltage, one side of the machine being grounded.

The generator used is of the Rosenberg type. As it is extremely desirable to eliminate the storage battery, the field is connected as a shunt. An extra precaution to maintain conditions approximating storage battery excitation is the insertion of the resistances R_1 and R_2 in series with the field winding. These resistances are to be made of fine iron wire in a tube containing an inert gas. The cross section is such that the wire at normal current operates at a dull glow. This gives it a high temperature coefficient. Thus, if for any reason, the voltage at the terminals of the generator should rise, the machine instead of building up cumulatively, would have the field resistance greatly increased cutting the value of current down to normal again. Ordinarily the voltage will stay constant and the device merely acts as a preventive device. As a further preventive device, a fuse is placed in the short circuit between b and b'. It will be seen that should the lamp circuit become open thru a break or the blowing of a fuse, while the generator is running, there will be no demagnetizing armature reaction acting against the original flux (ϕ_m). This will give a very high short circuit which in turn will cause

a dangerously high voltage to be produced between the brushes a-a'. By putting the fuse in the circuit b-b', this danger is avoided, for, when the short circuit current becomes too large, the fuse will blow, and there will be no voltage between a' and a. The iron wire resistance R_1 and R_2 in the field have the same protecting effect as a far too high voltage at the terminals of the machine will cause these already hot wires to melt. The method of calculating the resistances is given under the system describing the use of resistances of large temperature coefficients. The design of the field coils depends upon the value of resistance used as well as upon the winding of the armature. As the armature is to run at a fairly high speed, but little allowance need be made for increased copper cross-section due to the short-circuit current. It will be noticed that the resistance of the field circuit is divided into two parts. This is done to enable the generator to be used for lighting the interior of the car only, or the interior and headlight at the same time. When the headlight switch is closed, a current flows thru the coils of the magnet A. This picks up its armature closing the contact at B and throwing R_2 in parallel with R_1 . This allows more current to flow thru the field, causing the generator to balance at a higher current. If in place of an arc, a 400 watt 80 volt tungsten lamp be used, the operation of the system will be improved, as this would reduce the variation of current and voltage to which the arc is subjected which in this case is particularly undesirable, due to the constant current characteristics of the generator.

The question of motor power to drive the generator is not easily settled. Each type of motor has its advantages as well as its disadvantages. The series motor is the only machine that can be started at full line voltage. The series machine will also stand more rough usage and excessive voltage variation than any other type. But it has one drawback that is serious enough to make its adoption for this condition unfeasible. This is its variable speed. When delivering constant power, the speed drops off very rapidly with the voltage. A drop in voltage from 500 to 400 would decrease the speed by probably 50%, while an increase in voltage would cause the speed to increase proportionately faster. It is desirable, all things considered, to have the speed of the set as uniform as possible without introducing too many complications. The shunt motor has the great advantage of almost constant speed at constant voltage and varying load. It also partakes of this characteristic to some extent when operating at variable voltage. Plate 10 showing the performance curve of a shunt motor operating at a constant output and variable voltage. This curve was obtained from tests where the constant load was obtained by loading the motor with a generator, the generator output being kept constant by varying the field so as to keep the voltage constant on a constant resistance. The generator losses may vary a little with a change of speed, but this inaccuracy is too small to be considered. The motor in the proposed motor-generator set acts under the same conditions, i.e., the generator output is constant regardless of speed. An inspection of the speed curve shows that if extended it would cut

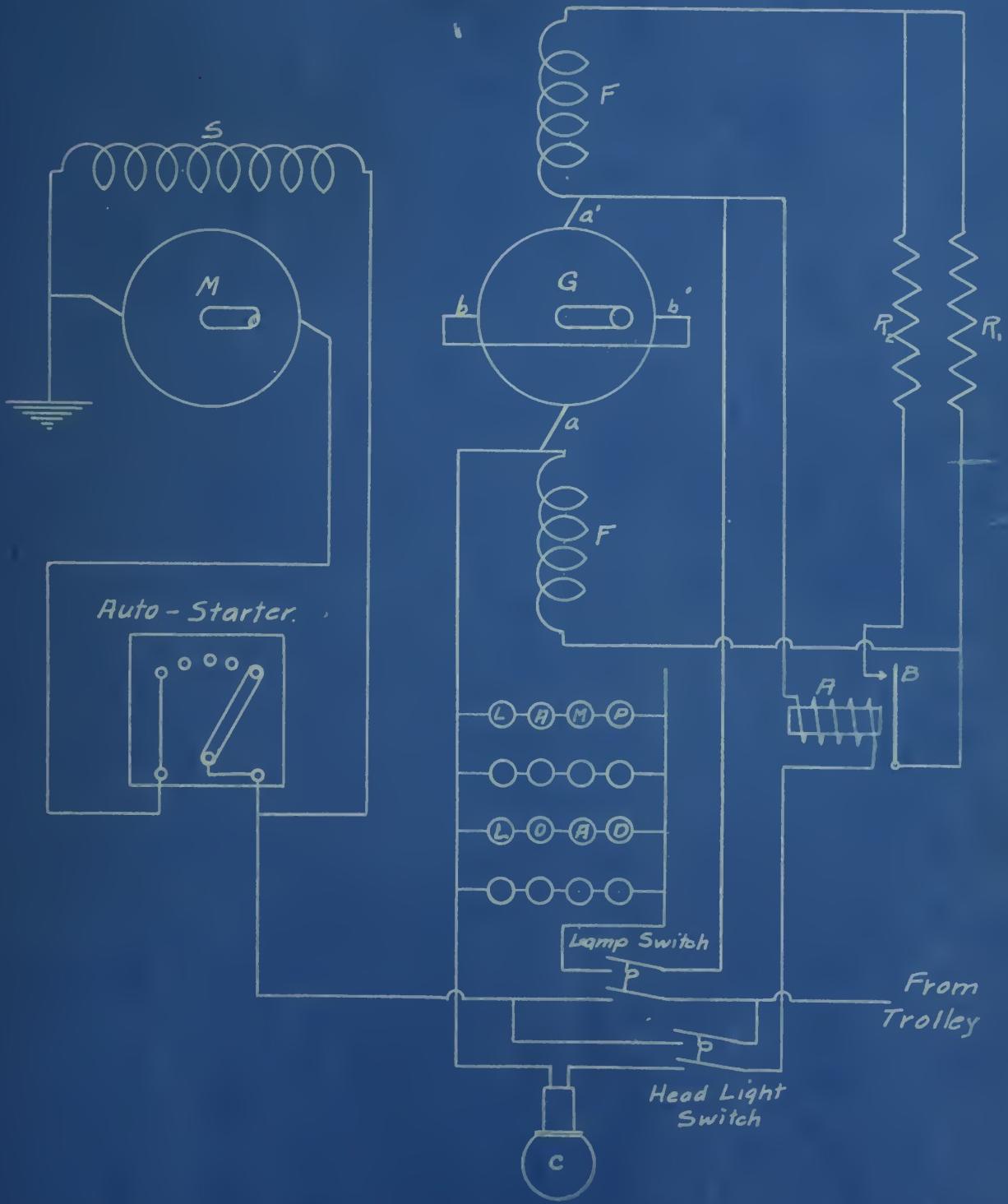
the vertical axis just above the origin. This means that at constant output, the speed does not change as fast as the voltage. If the motor is operated over a range of 300 to 550 volts, the generator should be so designed that at the speed corresponding to 300 volts, the generator current should be well on the flat part of the curve. Then any increase in speed due to the changes in voltage from 300 to 550 will cause only a very slight change in current. In the design of the motor, the motor current curve comes in handy. It is seen that the current increases as the voltage decreases, the curve taking the form of a hyperbola. The motor copper should be designed to operate at a mean voltage which depends upon the different values of voltages, while the insulation should be designed for a maximum of say 600 volts. If the average voltage on the line is low, the copper section must be made correspondingly large to allow for the increased current. If the average voltage is high, while open to large drops, the design can be made smaller as the drops will be of short duration and the increased current for the short period will not have much effect in heating the motor. A slight differential compounding, which would make the field weaken faster than the voltage, would tend to hold the speed of the motor more constant at the varying voltage. However this presents a complicated problem. The motor current in this case would rise faster even than that shown in Plate 10 for the shunt motor. If the differential field were a series winding, there would be danger that when the voltage became low, the machine would run away, as the two opposing fields became equal to each other and reverse when one

field overcame the other. The precautions necessary to prevent this, as well as the extra starting devices needed, would make the system far too complicated for the slight improvement obtained in motor regulation.

The shunt motor used in this set must have a starting device. As the design of the motor is rather rugged, the armature will take large currents without any harm. The starting steps can therefore be made few in number. The best method of accomplishing this starting is thru an auto-starter. This is an automatic solenoid operated device which cuts out the starting resistance step by step as the current reaches certain values. These automatic starters can be bought in all sizes on the market, and it is perhaps preferable to have one of these, rather than put the starter in the car cab with the switch lights. It will be seen that the motor current is lead thru a switch which is fastened to the lamp switch. Thus when the lights are wanted the lamp switch is closed. This closes the light circuit and the motor circuit at the same time.

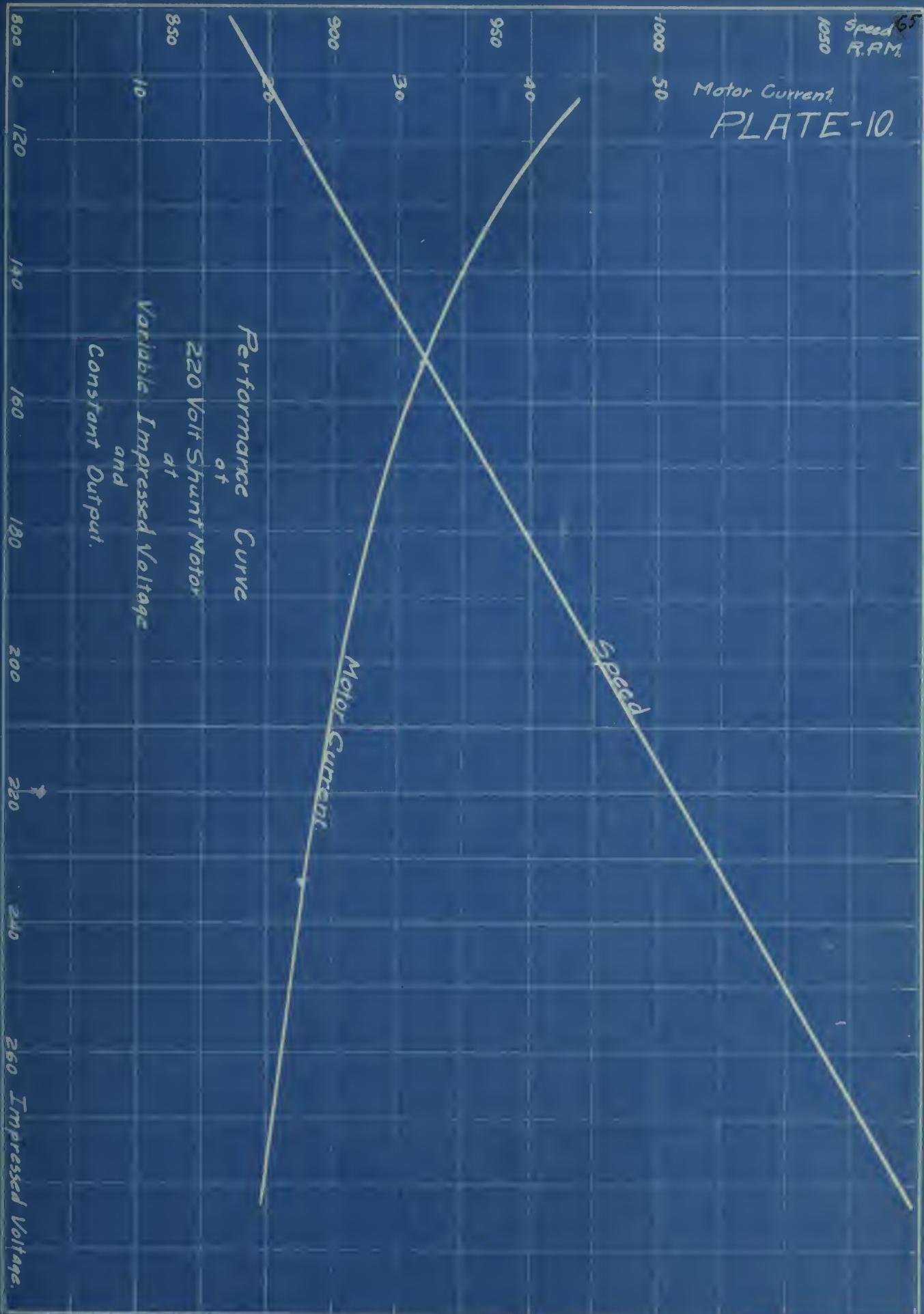
The motor and generator should be built on one base. The connection between the armature shafts should be ^aflexible coupling which can be readily removed. The brushes, especially of the generator should be readily accessible, while provision should be made for the easy removal of armatures. The whole set should be enclosed in a dust proof casing of some sort, and mounted underneath the car like the air compressor with its motor.

MOTOR GENERATOR
Car Lighting Scheme
with
Rosenberg Generator.



Speed
R.P.M.

Motor Current.
PLATE-10.



THE RESISTANCE OF HIGH TEMPERATURE COEFFICIENT.

The resistance of an electrical conductor undergoes a certain change when the temperature of the conductor is changed. The amount of this change depends upon the substance. The general change of resistance may be expressed by the equation

$$R = R_0(1 + at + bt^2 + ct^3),$$

where R is the resistance at the given temperature t_1 and R_0 is the resistance of the conductor at zero degrees centigrade. a , b , and c are constants that depend upon the material. A study of the tables of Landolt and Börnstein shows that while many metals and other substances have the property of increasing resistance with increased temperature, in few of these does the factor $(1 + at + bt^2 + ct^3)$ take on a high value at a reasonable temperature. Iron, steel, and cadmium give the best values. For cadmium the value of the coefficients at 318° is found to be 2.49. This outside of the other two mentioned is about the best substance given in the tables in respect to resistance. But the melting point of cadmium is only 320° so this substance could not be readily used. Iron and steel, especially the latter give the best results. The curves shown at figure 1 Plate 11 show how the coefficient changes with the temperature. These curves were plotted from the formula as described, up to the limit (1000°) for which the formula holds. If plotted beyond this temperature, from same formula, it will be seen that the curve becomes more and more vertical. This means that a slight change in temperature will cause a correspondingly large resistance change. This effect increases as the temperature increases, but

.there is a theoretical limit set by the melting point, and a practical limit far below due to the mechanical weaken^{ing} of the wire and to the necessity of radiation from the resistance.

Figure 2 shows results obtained by Kohlrausch in 1888 in tests of a slightly different nature. These tests were made for the purpose of finding the relation of magnetism and resistance to the density of the current pure electrolytic metals. The curve shows that at a density of 20 amperes per square millimeter , the specific resistance of the iron changes rapidly for slight changes of current density. Unfortunately the article, from which this curve was taken does not give the temperature. The change in resistance is due to perhaps more to the change of temperature caused by the change of current, than to the current itself. For this reason, the size of the wire and the conducting properties of the enclosing vessel play an important part in conditions where the fluxtuatuins of current density is continued. In these tests as well as in those resistances used in the Rosenberg scheme, the iron was enclosed in an atmosphere of inert gas to prevent oxidation. In the latter scheme the resistance is composed of fine iron wire which is coiled inside a tube containing nitrogen. As the wire is small, the current density, even for the small lamps currents is large, the effect being, that at normal current, the iron wire is at a dull red heat. As the variations in current in this system are slow, the radiating power of the gas and glass is sufficient to hold the wire at a temperature approximately proportional to the square of the current flowing, and to the resistance. That is for

slow changes, the temperature is approximately proportional to I^2R . Thus any small change of current in this system causes a considerable change of temperature, which in turn causes a large rise in resistance, the temperature, current and resistance all working in the same direction to reduce the rise in current and vice versa when the current is too low. An example of the effectiveness of this resistance is shown by an example given, when a change of current from 8.0 to 8.7 amperes produced a change of 41% in the resistance.

In the case of field resistances of the generator in the proposed motor generator scheme, the type of resistance described above would be satisfactory as there is little tendency for the current to change.

Taking up now, the suggestions that a resistance be put in series with the lamps to take care of the voltage drop, by keeping an approximately constant current. Several methods of connections at once suggest themselves. The lamps may be connected in straight series sets with each set of lamps having its own high coefficient resistance. The lamps may be connected in series parallel with a single resistance in series. Or we may have any combination of the two. We will assume that the system is devised to operate over a voltage ranging from 400 to 550 (a conservative estimate). This means that at the lower voltage, the resistance of the lamps plus the high temperature coefficient resistance must be such as to allow normal or perhaps slightly undernormal current to flow. At the higher voltage the resistance of the carbon lamps is slightly,

although negligiblly less, and the high temperature coefficient must increase in value enough to compensate for the increase of 150 volts. Taking the case of a single series set of lamps in series with a single resistance, we have for 16 c.p. carbon filament lamps a current of .5 amperes. From the curve of figure 2 we see that a density of about 20 amperes gives a great change of resistance for a slight change of current. This gives us a cross-section of $.5/20 = .025$ square millimeters. But this density is too near the melting point i.e. if the voltage is increased the iron will melt before its resistance has properly changed. If we allow say 10% variation of light, the voltage or current has a permissible range of about 3%. If for a trial, we connect two lamps in series with enough resistance to make up the drop we have the following. At 400 volts total resistance equal 800 watts of which the lamps have 400 watts leaving 360 for variable resistance. At 550 volts, the resistance equals 1100 watts of which 440 is lamp resistance, leaving 660 for the high temperature coefficient resistance. Thus the resistance of 360 watts is to change to 660 watts with a given change of current. If we take a current density of say 19 amperes per square millimeter at the start, the desired change is obtained when the current changes about 1.5 amperes in density or 7.5% instead of the required 3%. However if the ratio of the high temperature coefficient resistance to lamp resistance is increased this change of current can be reduced. Take for example the case of one lamp in series with the resistance. In this case at 400 volts we have $800 - 220 = 580$ watts as the variable resistance while at 550 volts

we have $1100 - 220 = 880$. Thus the change from 580 to 880 with an original density of 20 amperes per square millimeter is accomplished thru a change of current density of about .6 amperes. This is a change of $.6 / 20 = .03$ which will give about 10% lighting variation. Besides this, it must be borne in mind that this variation brings the resistance to a high temperature when the voltage is high. The efficiency of this system however is so poor that it effectively prevents its adoption. Only one fifth of the power furnished, is used in lighting at the high voltage, while at the low, slightly more than one fourth is used. This, for efficiency puts it in a class with the arc lamps as the latter is used on cars. This low efficiency takes place whether the lamps are arranged in any of the three connections mentioned above. But there is still another objection to the use of this resistance for regulating the voltage. In order to follow the voltage changes with any degree of closeness, it is necessary for the resistance to be of such a mechanical construction that the radiation will be almost instantaneous. Owing to the fact that this wire must be surrounded by an inert gas, this is almost impossible. The fineness of the wire (.025 sq.mm.) together with the high temperature at which it works makes the device very fragile, and in order to prevent breakage, the resistances are so mounted that the vibration of the car affects them but little.

In conclusion, it may be said of this scheme, that while on first sight this scheme may look good, the mechanical difficulties, to say nothing of its efficiency, prevents its use in the manner described. It has however a good field for regulating small currents

where the whole power in the circuit does not amount to much and the resistance of high temperature coefficients can be made very large in comparison with the resistance in series with it. Where small and slow changes are required, such as those due to difference of voltage of a storage battery at charge and discharge, this system, while not very efficient gives good regulation.

PLATE-11

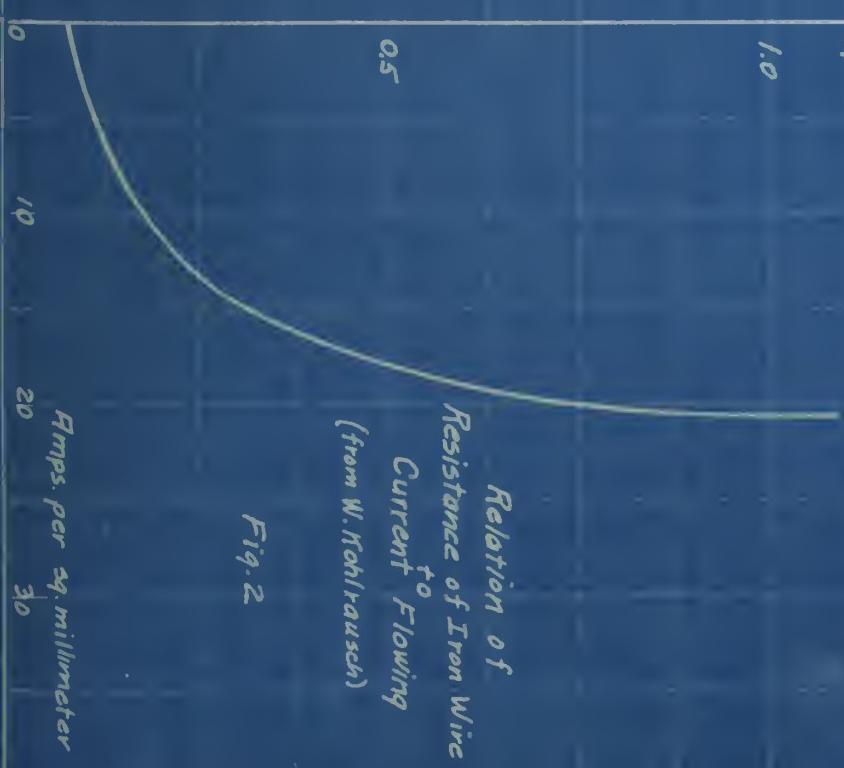
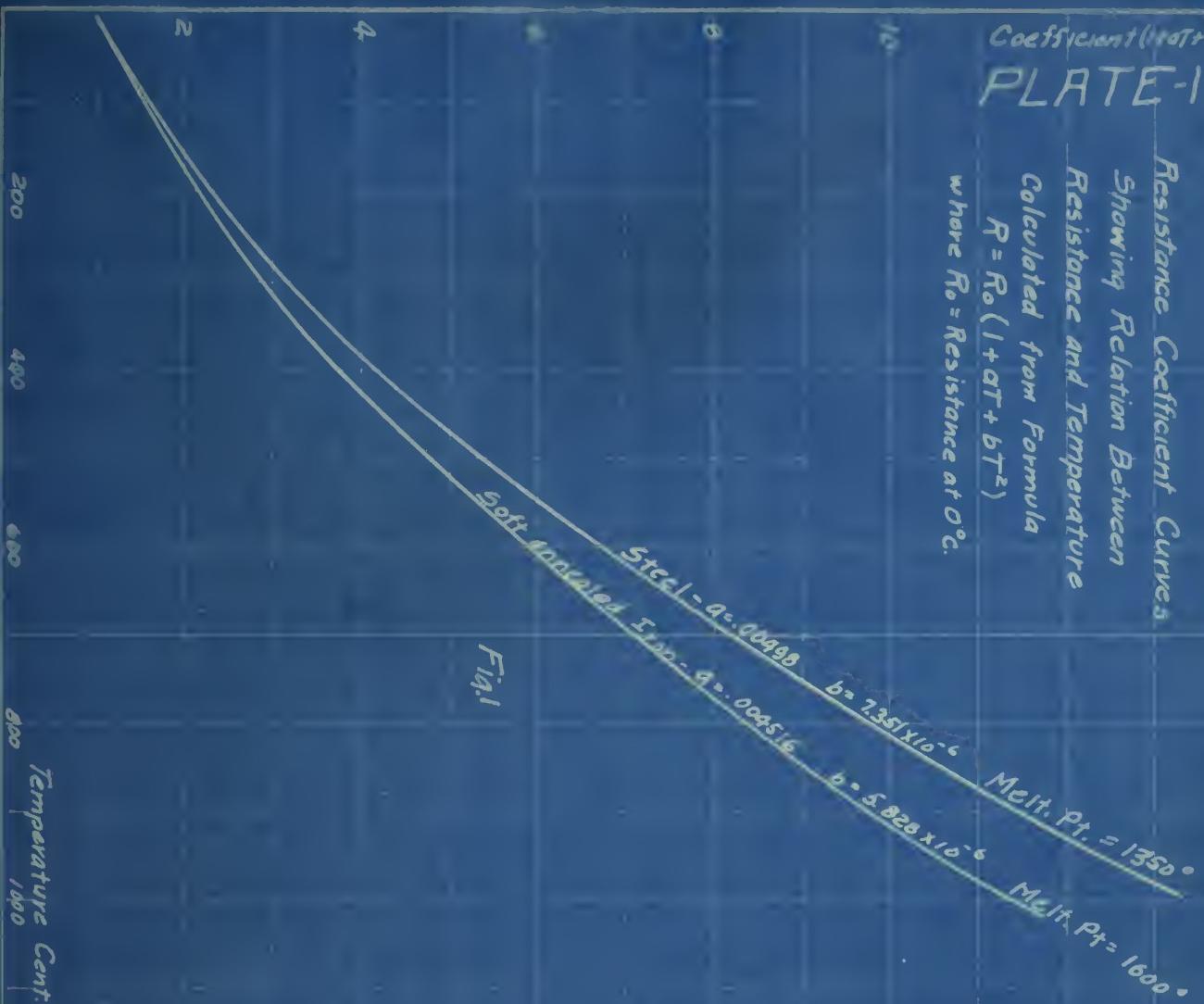
Resistance Coefficient Curves

*Showing Relation Between
Resistance and Temperature*

Calculated from Formula

$$R = R_0(1 + \alpha T + \beta T^2)$$

where R_0 = Resistance at 0°C .



THE CARBON PILE REGULATOR.

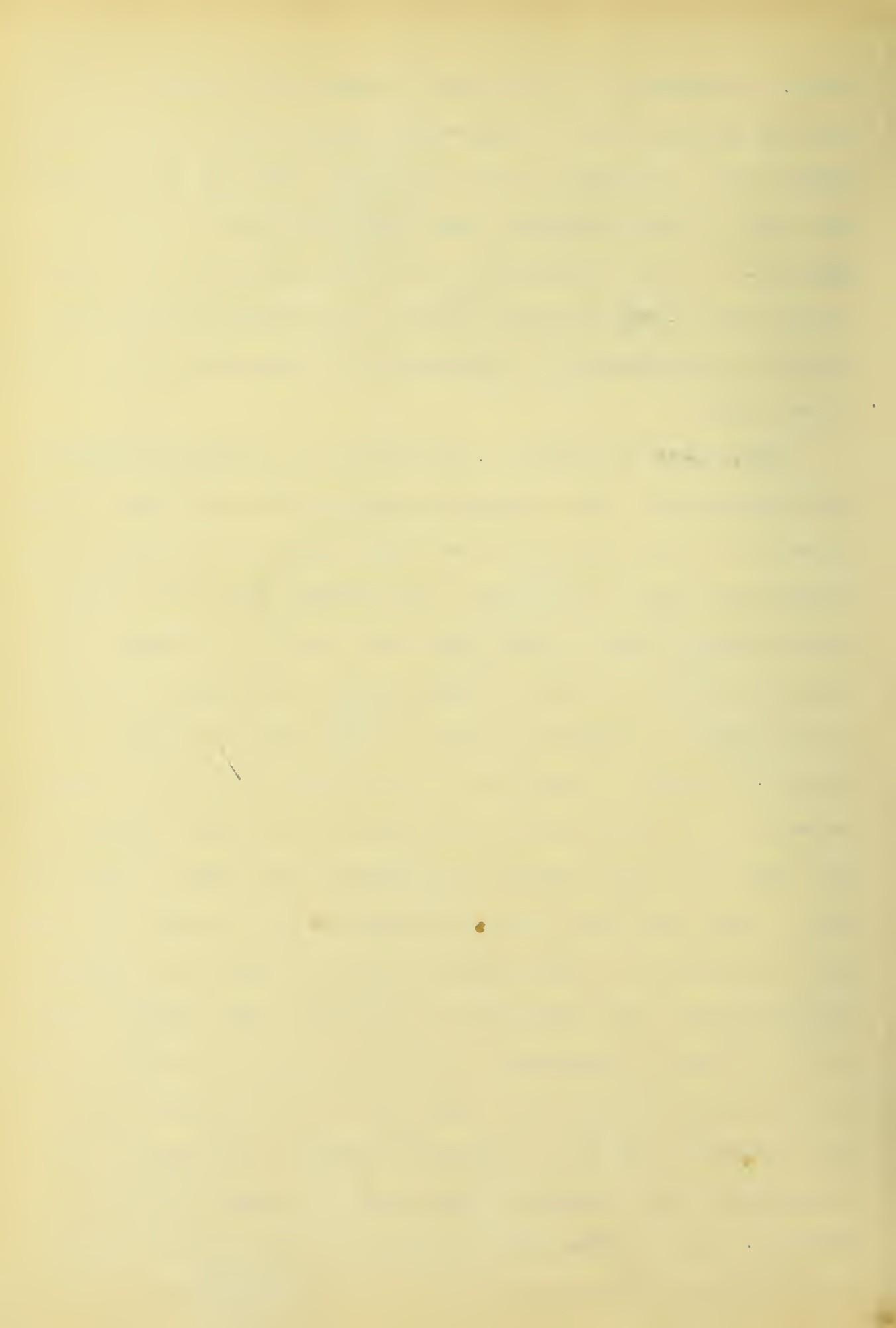
On account of its simplicity, lack of moving parts and direct regulation of voltage, the carbon pile suggests itself as a solution of the car lighting problem. The general scheme is to have a series of thin plates or discs, this pile being connected in series with the lamps to be regulated, and the whole to be placed across the line. The change of resistance of the carbon pile is to effect the regulation, and this change is to be accomplished by changing the pressure on the pile thru a solenoid which is operated by current from the varying trolley voltage.

In order to determine just how the carbon would act under the change of pressure a test was made. The apparatus consisted of a board with two parallel strips. Into the slots made by the strips, a pile of carbon discs was placed. The discs were ordinary arc light carbons sawed into quarter inch lengths. The two end carbons were made longer, and had holes drilled in them. Brass terminals fastened to the end pieces were held in place by casting lead around them. One end carbon was fastened, while at the other, pressure was applied thru a lever. The pull on the lever was transmitted thru a spring balance, which with the lever ratio gave an accurate value of the pressure exerted.

The prime object of the test was to find the relation between resistance and pressure. The test was made as follows. With a given current flowing, and the carbon at highest compression the current thru and the drop across the pile was read. The pressure was then reduced and after current had been adjusted to former

value, the readings of current and voltage were repeated. This was continued until zero pressure was reached, when a new test was started with a different value of current. From the data obtained the value of resistances were calculated and plotted as shown in Plate 13. It will be noted that the current density has no particular effect, the difference between the different curves being caused by the difference in temperature of the carbon pile at different tests.

With these data at hand, the design of a suitable apparatus was investigated. With the system proposed, the resistance of the carbon pile would have to increase with increase of voltage. The pressure-resistance curve shows that pressure would have to decrease with increase of resistance and therefor of voltage. The solution of this is to have a spring which acts against the pull of the solenoid as shown in Plate 12. Thus when the voltage increases, the pull of the solenoid is increased and the resultant pressure on the carbon pile is decreased. The limits between which the carbon pile can be worked are limited on one side by the tendency to crush and break under high pressure, and on the other side by the necessity of having enough pressure to keep the discs from being displaced and rattled due to vibration, thus causing carbon dust to change the resistance. The upper limit of pressure is also limited by the fact that the resistance does not change much at high pressures even for a considerable change of pressure. An inspection of the resistance curve shows the proper range to be between .4 and 1.2 ohms which corresponds to pressures of 30 and



2 pounds. That is the pressure varies from 1 to 40 while the resistance varies from 1 to 3.

If now we assume a variation of trolley voltage between 550 and 350 we have the following. Let x be the RI drop over the carbon pile resistance when the resistance is lowest. Then $3x$ is the drop when the resistance is highest. As the voltage at lamps should be constant and is the difference between trolley voltage and carbon pile drop, we have $550 - 3x = 350 - x$ whence $x = 100$, which leaves 250 volts across the lamps. If we are using say 30 - 25 watts tungsten lamps we have the current of $(30 \times 25)/250 = 3$ amperes, which means that the resistance varies between the limits of 33 and 100 ohms. By making the pile of suitable length and cross-section this may be obtained. It is desirable, in view of the heating, to increase the length rather than increase the diameter, to obtain this result. The solenoid pressure varies directly with the voltage and is a function of the position of the solenoid core. If we assume no movement of the core, we can obtain perfect regulation at the two limiting voltages, but as the pressure on the carbon pile would be a straight line function, the regulation would not be effected at points between. However, it is desirable to have as small a power loss in the solenoid as possible and for this reason a large leverage would be used. This means that the solenoid core would travel an appreciable distance between upper and lower voltages. By designing the apparatus so that the solenoid core is above the position of maximum pull, when the voltage which is lowest, and at the position of maximum pull when the

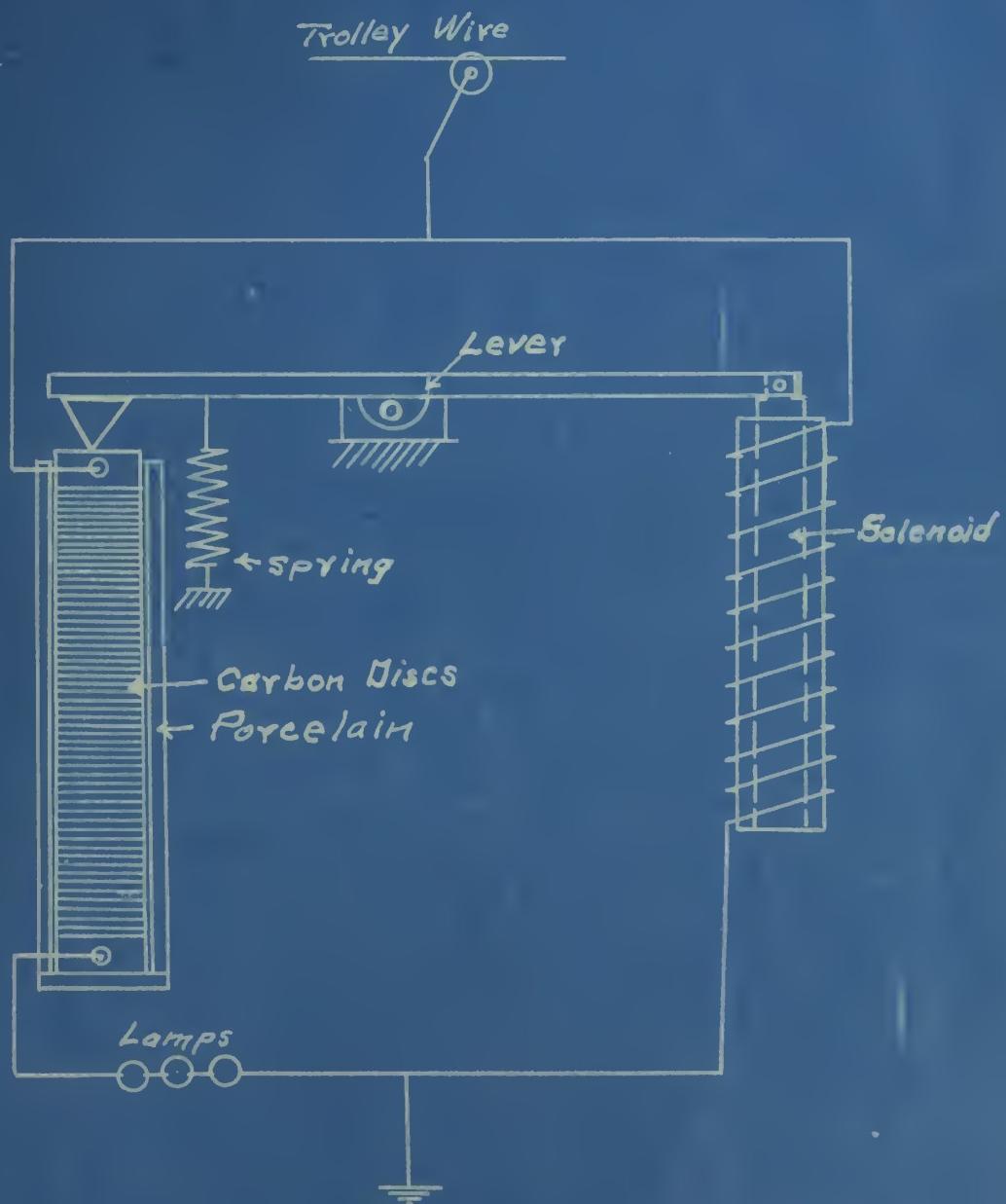
voltage is highest, the solenoid pull can be made to increase faster than the voltage. This means that the resultant pressure on the pile decreases faster than the voltage increases, which will cause the resistance to increase about as the voltage, keeping the voltage at the lamps constant for any position, i.e. for any value of trolley voltage.

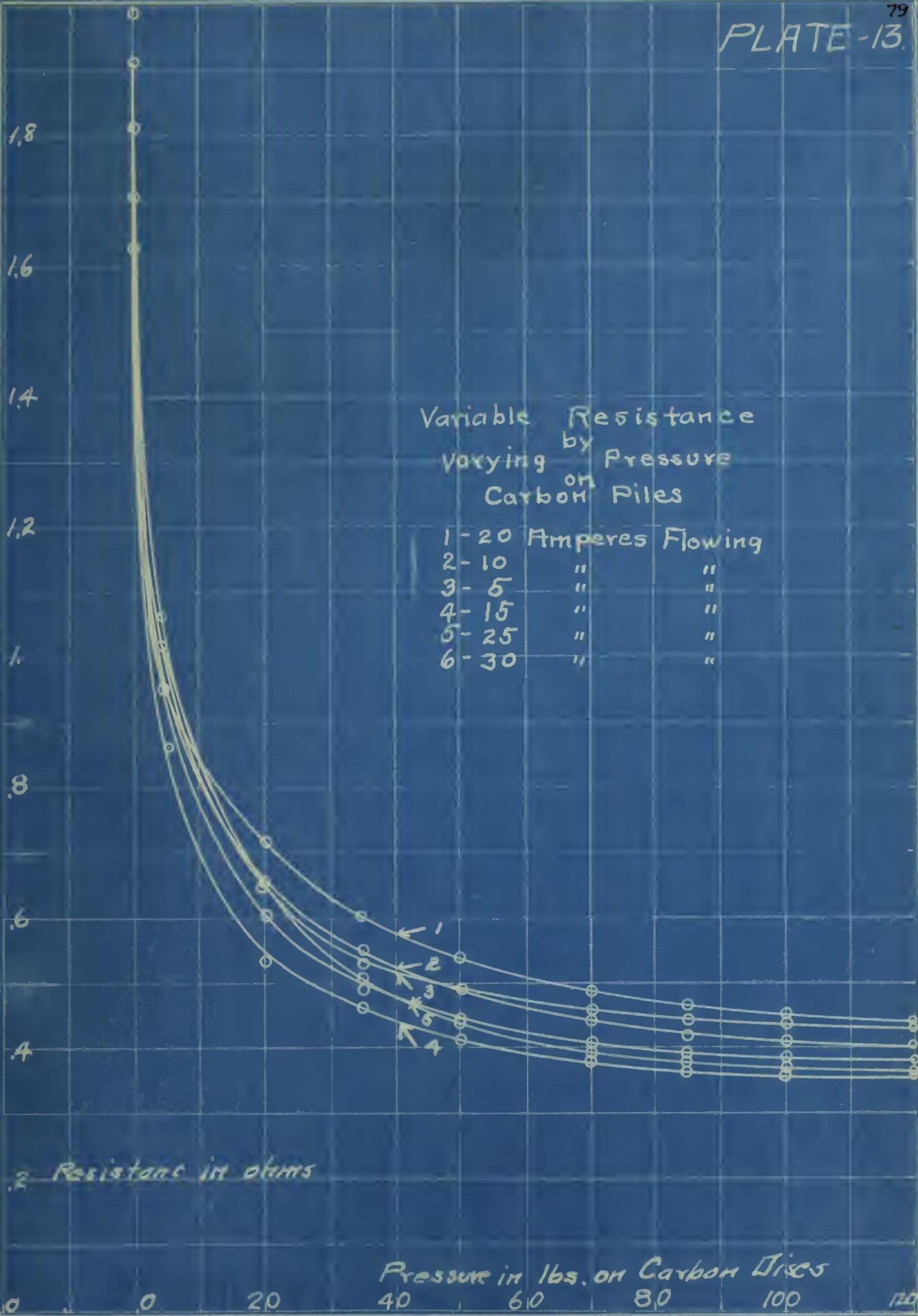
The chief drawbacks of this apparatus are its delicacy, its inefficiency and the difficulty of radiating the heat lost in the pile. In order to obtain close regulation, the friction in the solenoid and in the bearings must be small. The adjustment of the balancing spring and the resistance will have to be delicate as well as the location of the solenoid core. The constant movement of the carbon discs on each other will cause rapid wear which will change the resistance continually. If small carbon particles are used instead of discs, there is great liability of them becoming packed. The efficiency of the apparatus is highest at the lowest voltage, and lowest at the highest voltage. With normal running voltage of say 500 volts the efficiency is a little less than $250/500 = 50\%$ due to the power used in the solenoid.

The problem of radiating the heat lost in the resistance is the most serious. The cars running most of the time at normal voltage of say 500 volts. This gives a resistance loss of $I^2 R = 3 \times 3 \times 250 = 2250$ watts which is equal to the heat given up in all lamps. As the pile must be inclosed to keep out dust it is necessary to have a non-conducting vessel which will radiate the heat rapidly. Even then, the pile must be made of large cross-section

and considerable length so that the heat loss is not concentrated, as this would cause the carbons to become hot and decrease the resistance, which would affect the regulation.

DIAGRAM
OF
CARBON PILE and SOLENOID
VOLTAGE REGULATING APPARATUS
FOR
DIRECT CURRENT





APPENDIX.

COMPARISON OF ELECTRIC LAMPS.

Mr. T. H. Amrine of the University of Illinois engineering experiment station published in Bulletins 19 and 33 results of tests on electric lamps. The tests made cover all types of electric filament lamps, as regards efficiency, life, cost of operation, ability to withstand rough usage, susceptibility to voltage variation and quality of light.

The object of this comparison is to show the relation of the various kinds of filament lamps to each other as regards candle power and voltage regulation.

The curves of Plate 14 show the effect of voltage variation compared to the horizontal candle power for the various kinds of lamps. From the slope of the curves, the tungsten lamp shows the least variation of horizontal candle power for a given change of voltage, while the carbon lamp shows the greatest candle power for a given change of voltage on the lamp. The tantalum lamp has a slightly greater candle power variation than the tungsten, while the metalized is lamp is but slightly better than the carbon.

The carbon lamp is able to withstand very rough usage, while the tungsten is very susceptible to vibrations and rough usage. Hence the carbon lamp is well adapted to car lighting as regards rough usage, but has a poor candle power-voltage regulation. The tungsten lamp when made for higher voltages is very delicate and easily broken. The tantalum lamp gives a white light like the tungsten, is more hardy, and has been used on some electric inter-urban cars.

The tantalum and tungsten lamps having metal filaments have a positive temperature coefficient, hence when the lights are turned on a sudden flash of light takes place due to the low resistance. The carbon lamp has a negative temperature coefficient hence it does not flash when the lights are turned on.

The candle power-voltage characteristic curves were plotted from the following formulae obtained from experimental data.

Carbon lamps.

$$\text{H.C.P.} = 143.5 \times E^{5.97} \times 10^{-13}.$$

Metalized lamps.

$$\text{H.C.P.} = 507 \times E^{5.2} \times 10^{-11}.$$

Tantalum lamps.

$$\text{H.C.P.} = 166.4 \times E^{4.45} \times 10^{-10}.$$

Tungsten lamps.

$$\text{H.C.P.} = 213.7 \times E^{3.44} \times 10^{-8}.$$

80

70

60

50

40

30

20

10

Horizontal Candle Power
of Lamps

Carbon
Metallized
Tantalum
Tungsten

Curves Showing
Relation of Candle Power
of Various Electric Lamps
Impressed Voltage

90

100

110

Voltage on Lamps
120 130

140





